Order Number 9035358

An evolutionary approach to archaeological inference: Aspects of architectural variation in the 17th-century Chesapeake

Neiman, Fraser Duff, Ph.D.

Yale University, 1990

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

An Evolutionary Approach to Archaeological Inference: Aspects of Architectural Variation in the 17th-Century Chesapeake

A Dissertation

Presented to the Faculty of the Graduate School

of

Yale University

in Candidacy for the Degree of

Doctor of Philosophy

by

Fraser Duff Neiman

May 1990

Abstract

An Evolutionary Approach to Archaeological Inference: Aspects of Architectural Variation in the 17th-Century Chesapeake

Fraser Duff Neiman
Yale University
1990

The current preoccupation of archaeologists who still embrace the goals of the New Archaeology with "middle-range theory" is a hindrance to the development of a progressive, scientific research program. What is required is renewed emphasis on the development of fundamental theory. Neo-Darwinian theory offers a promising starting point. However, neo-Darwinian processes and models do not offer a causally or dynamically sufficient account of behavioral dynamics for species among whose members social learning is an important determinant of phenotypic variation.

Explicit (mathematical) models of cultural transmission recently developed by Cavalli-Sforza and Feldman and especially Boyd and Richerson are crucial to inferring the causal mechanisms responsible for variability in the archaeological record. Mechanisms may be divided among those that introduce variability into populations (guided variation, random variation, migration, indirect transmission), those that sort it in a deterministic fashion (selection, direct bias, indirect bias), and those that sort it stochastically (drift). Linking the models to a picture of site formation as a time-averaging process, allows the derivation of contrasting expectations for patterns of behavioral change under different forces that can be rendered in terms of patterns manifest at the assemblage level in the archaeological record. Evolutionary mechanisms that cause deterministic sorting are the basis for inference of behavior from artifacts.

Just how an evolutionary approach works in practice is illustrated in a case study of change in house plans and site structure found on English plantation sites in the Chesapeake Bay region in the 17th and early 18th centuries. An examination of temporal variation in house plans reveals deterministic sorting of variant means of organizing plantation production in the region as a whole. Delineation of temporal trajectories of stylistic and functional variants in the archaeological record of The Clifts Plantation Site (44WM33) helps isolate its causes. Multivariate analyses of assemblage composition through time and of intrasite artifact distributions in space identify stylistic and/or wealth-related differences between successive occupants and correlated differences in the layout and use of architectural space. The pattern of change indicates economic failure and consequent replacement of an original group of occupants by individuals practicing new organizational strategies that minimized costs associated with provisioning, maintaining, and monitoring plantation workers. Architectural changes were the outcome of a mechanistic process in which individuals practicing different strategies of production organization were subject to different rates of economic failure and thus contributed organizational prescriptions to social learning networks at characteristically different rates. As a consequence, certain plan forms and associated production strategies disappeared from the Chesapeake cultural repertoire during the late 17th century.

Preface

Many people have contributed in a variety of ways to the completion of this project. The least I can do is acknowledge the help of some of them here.

Courses with two former members of the Department of Anthropology at Yale, John Rhoads and David Pilbeam, introduced me to the notion that evolutionary theory offered a key to the principled understanding of historical processes. John Rhoads impressed upon me the importance of the quantitative description of empirical variation and its meaninglessness without theoretical motivation. I am grateful to them for suffering the presence of an historical archaeologist in their classes. I have also learned a lot from my fellow graduate students, especially Dave Killick, Tom Dye and Jeff Rogers. I am indebted to Micheal Coe, my adviser, and to Frank Hole. They both have exhibited a great deal of patience while awaiting completion of this work and fortitude while reading it.

The work of Robert Dunnell is obviously the primary theoretical inspiration for this dissertation. He has earned special gratitude for agreeing to read it, thereby subjecting himself to what I fear may seem a perverse rendering of many of his ideas. I sincerely appreciate his efforts.

I have accumulated many debts to archaeological, architectural, and historical colleagues in the Chesapeake. Foremost among them is William Kelso, who introduced me to the field and to fieldwork, and provided the opportunity to participate in the former by doing the latter. Cary Carson and Dell Upton taught me that systematic sense could be made of the archaeological record of the region, showed by example how it might be done, and encouraged me to try my hand at it. Members of the archaeological branch of the St. Mary's City mafia, among them Garry Stone, Henry Miller, Robert Keeler, and the late Sandy Morrison, provided helpful discussion and advice that immeasurably improved the quality of data recovered from The Clifts. They and especially Julie King have contributed to my appreciation of the precariousness of inferences based on plowzone artifact distributions. Alain Outlaw, Nick Luccketti, Andy Edwards, Dave Hazzard, Tony Opperman, Ann Markell, Taft Kiser, and James Deetz have also generously contributed both data and ideas on its interpretation that have forced me to reevaluate and reject a few pet hypotheses. I am grateful to Joanne Bowen Gaynor for analyzing the faunal material and to the late Larry Angel for his analysis of human skeletons from The Clifts. Foremost among the contributors to The Clifts project is Janet Long whose organizational and analytical skills in the lab and field were crucial to the success of the excavation. I am fortunate to count these people as friends as well.

I am also deeply grateful to The Robert E. Lee Memorial Association for sponsoring the excavation of The Clifts. The Association's Executive Director, Admiral Thomas E. Bass, III (USN, Ret.) was an unflagging source of practical help and good guidance. The Association's Directors provided the vision that initiated archaeological research at Stratford in the first place and support along the way. I am especially grateful to Mrs. William Hunter de Butts, Mrs. Landon Carter Wellford, and Mrs. Leslie Cheek for their great personal kindness, while suffering my assaults on their historical sensibilities. The excavations were funded through a generous grant from The Lilly Endowment, Inc.

I am grateful to Georgia Jennings and my other friends in the business world for providing regular, much-needed respite from the chronic graduate student condition, helping to insure I survived it. Georgia Jennings deserves special thanks for allowing me the leave of absence that enabled me to complete this dissertation.

Barbara Carson, Cary Carson, Dennis Pogue, and Glyn Fergurson Pogue have been the best of friends and intellectual companions throughout. So has Martha Hill, without whose encouragement and advice, I would still not be working on Chapter 1. My debt to her is very great.

While all of these individuals and many others share credit for any merits in what follows, I alone am responsible for logical lapses lurking in the argument. There are doubtless many, many more than I would like to think. I wish readers the best of luck in finding them.

Table of Contents

List of Figures

List of Tables

Introduction

Over a decade ago, Robert Dunnell raised the possibility that Darwinian evolutionary theory might prove to be the foundation for a progressive research program in archaeology (1978, 1980). However, at a time when the archaeological literature is increasingly filled with programmatic statements advocating a wide variety approaches to the archaeological record, expressions of interest in an evolutionary archaeology remain sporadic at best. While the reasons for this are complex, prominent contributing factors are surely the following. First, most archaeologists either ignore or misconstrue the importance of the development of explicit theory to their enterprise. Second, even for those who sense the importance of theory, just why an evolutionary approach should be preferred over any other is obscure. Finally, it is not altogether clear just what an evolutionary archaeology will really look like in practice. Just how can an evolutionary approach be implemented and how is it different from other ways of making sense of the archaeological record? This dissertation offers one set of answers to these questions.

There is a great deal of ground to be covered so a map of the terrain may be helpful. In Chapter 1 I suggest, contrary to the modal archaeological opinion, that fundamental theoretical issues are crucial to further progress in the discipline. Current archaeological preoccupation with "middle-range" theory is counterproductive. The goal of middle-range theory, inferring the behavioral significance of artifacts, requires fundamental theory about the causal processes behind human history. I outline some of the consequences of choosing a mechanistic, evolutionary approach to fundamental theory development over more traditional perspectives on human behavior.

Chapter 2 offers an outline of the structure of evolutionary theory drawn from neo-Darwinism. It suggests that the ills of "middle-range" theory are the predictable consequence of archaeology's inattention to the mechanisms that cause variability in human behavior. I then move on to a consideration of sociobiology as a candidate fundamental theory for archaeology. I argue that accounts of human behavior based on unadulterated neo-Darwinism are deficient since they exclude explicit consideration of two mechanisms --individual and social learning -- that are important in phenotype determination of a wide variety of organisms, not just people. I argue that a dual-inheritance approach, that acknowledges the origins of learning in the natural selection of genetic variation but also offers explicit accounts of the novel dynamics introduced by learning, especially cultural transmission, is currently the most promising approach to the problem. The fundamental theory that archaeology requires is to be found in explicit mathematical models of evolutionary forces that cause the differential persistence of cultural information in time and space.

Chapter 3 offers some very simple versions of the requisite models for cultural transmission originally developed by Cavalli-Sforza and Feldman (1981) and especially by Boyd and Richerson (1985). The exposition proceeds like a population genetics text, reviewing models of the operation of different evolutionary forces that yield explicit expectations concerning the temporal patterns in variant frequency generated by each.

Chapter 4 describes how these models can be useful in making inferences about the causes of empirically documented temporal patterning in cultural variants. It provides a framework in which theoretical expectations concerning variation in cultural repertoires under different forces can be rendered in terms of the archaeological record. The models also make it possible to suggest in a more precise manner just what evolutionary processes are being invoked when archaeologists make inferences about behavior from artifacts. Finally, I suggest how two characteristics of complex societies -- social stratification and functional differentiation -- are likely to affect the operation of certain evolutionary forces. Coverage of this topic is necessary because the case study that comprises the rest of the work is drawn from just such a social context: the English colonization of 17th-century Virginia and Maryland.

Chapter 5 introduces this subject by outlining how English adaptive strategies in the Chesapeake were affected by environmental variation from two sources. First, physical-environmental variation encountered by English colonists as they invaded the region caused deterministic sorting of settlement strategies. The outcome can be monitored indirectly in variation in rates of settlement spread. I offer a tentative account of the evolutionary mechanisms behind the process. Second, variation in the greater Atlantic economy, including the demand for tobacco and the availability of labor, caused deterministic sorting of house plans and, I argue, variable means of organizing plantation production of which they were a part. In this case the availability of archaeological data makes it possible not merely to frame hypotheses about the causes of sorting, but also to test them by examining patterns of variation in the archaeological record.

A review of previous work on the topic suggests two hypotheses for the causes of sorting. Both invoke social-learning rules, the product of a prior history of natural selection, that cause the differential persistence of culturally transmitted means of organizing plantation production. Under the first, individuals use a learning rule to evaluate directly variant production arrangements on the basis of the extent to which they necessitate contact with a threatening and unfamiliar labor force. Here house-plan changes were a result of plantation owners' attempts to minimize contact with a labor force whose ranks were increasingly dominated by Irish and poor English indentured servants and finally by enslaved Africans. Under the second, social learning is guided by a more general-purpose rule that instructs owners to learn preferentially from other individuals who are economically prosperous. Under this hypothesis, architectural change is caused by variation among plans in economic efficiency, in the context of falling tobacco prices and rising labor costs. The final two chapters offer a test of the two hypotheses, based on archaeological evidence from The Clifts Plantation Site, a tobacco farm on the south shore of the Potomac River. The theoretical framework developed in the first four chapters makes it possible to infer the processes behind major alterations in the architectural fabric of The Clifts that occurred at the end of the 17th century. The evidence from The Clifts suggest that outmoded means of organizing production disappeared at this site, because plantation owners using them suffered adverse economic consequences.

Chapter 1

The Importance of Theory

1 Introduction

It has been more than more than twenty years since the New Archaeology set for itself the goal of transforming archaeology into a science. We have yet to see the apotheosis of a scientific archaeology. However, over the past two decades there has emerged a consensus, among those who still embrace the scientific goals of the New Archaeology, on the means by which the transformation is to be wrought and scientific knowledge about the past produced. This consensus suggests that the production of archaeological knowledge is a two-step process involving two distinct sorts of theory. Following traditional usage, I will refer to these successive operations as inference and explanation. In the first step, a reconstruction of behavioral transactions or system dynamics is inferred from the static archaeological record. The theoretical means to build reconstructions are called variously "behavioral archaeology" and "middle-range theory". They are comprised of general principles linking material remains to behavior. In the second step, an explanation of the reconstruction is offered. Reconstructions in turn are explained using general or high-level theory, that is general principles linking behavior to the determinants of history.

In this chapter I examine the ways in which this position is articulated in the writings of its two most energetic proponents, Michael Schiffer and Lewis Binford. Although both men go to great lengths to stress the differences between their positions on the proper means of handling middle-range theory (Schiffer 1985, Binford 1981a), their positions share important characteristics. Both emphasize middle-range theory at the expense of general theory, as does most of the recent theoretical literature. After an examination of the kinds of theory employed in archaeological inference, I argue that this ranking of priorities for the development of archaeological theory is unfortunate and that the distinction between middle-range and general theory on which it is based is fundamentally misleading. If it persists, it will guarantee that the scientific apotheosis of archaeology will never occur. Archaeologists still interested in the pursuit of that goal, glimpsed by the New Archaeology in the 1960's, need to redirect their efforts toward the development of general theory. Finally, I suggest some of the characteristics of a theoretical framework that might lead to the advent of a progressive scientific research program for archaeology.

1.1 Behavioral Archaeology

For Schiffer, archaeology must concern itself "first and foremost with devising principles and methods for reconstructing past behavior from archaeological remains" (1976:2), that is with inference. His program for the creation of the means for inference is behavioral archaeology. He is careful to suggest that its pursuit does not mean that attempts to explain the past should cease. However, it is clear where the priority lies. The principles that behavioral archaeology will develop to make possible archaeological inference fall into two major groups: principles governing the relationship between artifacts and behavior, called by Schiffer "behavioral correlates," and principles governing site-formation processes or "transforms." Behavioral correlates are principles or laws about the manner in which artifacts participate in a behavioral system, in other words how things were made and used. They "relate behavioral variables to variables of material objects or spatial relations" (1976:13). Behavioral correlates allow the inference of behavior from artifacts in Pompeii-like settings, where artifacts are not altered in condition and location from the "systemic context" in which they were originally used.

Site formation processes are alterations of the condition and location of artifacts from their original context of use. Schiffer distinguishes two classes of formation processes, cultural and non-cultural, governed by two distinct bodies of theory, c-transforms and n-transforms respectively. The distinction turns on whether the alterations in artifact context are caused by human or non-human agents, for example by cleaning house or by erosion. As a result of site formation processes, the archaeological record is a "transformed and distorted view of artifacts as they once participated in a behavioral system" (Schiffer 1983:677, see also 1976:12, 1972:156). The second aim of behavioral archaeology is therefore the construction of cultural and non-cultural transforms to identify and model the processes that brought together the artifacts found in a particular archaeological deposit. In the best of circumstances, the ultimate goal is the inference of the locations and conditions that formerly characterized those artifacts in their original context of use. In practice, the result is more often the identification of which deposits are transformed and distorted sufficiently so that their contents can no longer serve as the basis for inferences about behavior (e.g. Schiffer 1983:694-696). In either case, one wants to infer the character of the alterations in condition and location between the time they ceased being used by ancient people and were recovered archaeologically.

It should be noted in passing that Schiffer's original adumbration of formation processes was in a context in which there was no question that humans had been ultimately responsible for the genesis of the deposits under consideration. More recently, influenced by the independent emergence of taphonomy in geology and paleontology, the notion that formation processes are of interest only in the context of correcting distortions of evidence for human behavior has receded (Behrensmeyer 1984, Gifford 1981). In paleoanthropology, the demonstration that hominids created clusters of bones and stones has emerged as a major focus (Binford 1981b, Potts and Shipman 1981).

Thus archaeological inference is for Schiffer a two-stage process. Each stage has its own, unique set of principles. In stage one the principles governing site-formation processes are used to transform a distorted archaeological record into Pompeii or, failing that, to identify distorted deposits, which are subsequently eliminated from further consideration. In stage two behavioral correlates are employed to transform Pompeii into "behavioral and cultural variables" (1976:43). Taken together, these are the means by which "the explanation of archaeological observations is achieved" (1976:17). To Schiffer the resulting behavioral reconstructions are "explanations" of archaeological facts in a proximate sense only, that is within the framework of problems set by behavioral archaeology. In other words, they are inferences in the sense discussed above. In a larger context, which in his terms is not an archaeological one, behavioral reconstructions are simply descriptions, "documentation of the behavioral and organizational properties of past cultural system functions" (1976:2). They therefore are themselves the objects of further explanation.

Schiffer has essentially nothing to say about the manner in which explanation, the second aspect of the production of knowledge about the past, is to be undertaken. This silence is a consequence of Schiffer's belief that successful archaeological inference is a necessary condition for the introduction of explanatory arguments. Commenting on case-specific targets of inference like the Pueblo IV population aggregation, he suggests that "the explanation of systemic phenomenon (sic) ... is contingent upon the prior or concomitant explanation of the facts of the archaeological record" (1976:3). More generally he believes that "archaeologists cannot test high-level theories about culture change until the reliability of inferences is improved" (1985:193). In other words, the means for archaeological inference can be, indeed must be, fashioned before the development of theory for the explanation of historical processes is undertaken. Schiffer's silence on the question of what high-level theory ought to look like is an obvious weakness in his position that his critics, principally Lewis Binford, have exploited.

1.2 Middle-range Theory

Binford has gone to great polemical lengths to distinguish middle-range theory from Schiffer's behavioral archaeology (e.g. 1981a, 1986). However, by his own admission (1981b:25), the two have fundamentally similar goals. Binford sees middle-range theory as the means by which we convert the "static facts of the archaeological record to statements of dynamics" concerning cultural systems in the past (1977:6). The development of middle-range theory is supposed to provide "accurate means of identification, and good instruments of measuring specified properties of past cultural systems" (1981b:25). In other words, although Binford eschews the distinctions, middle-range theory covers what Schiffer calls correlates and cultural and non-cultural transforms. All are supposed to solve the same kinds of problems.

Binford is more explicit than Schiffer about general theory and its relationship to middle-range theory. General theory comprises the means by which archaeologists explain the characteristics of cultural systems past and present, "our theories regarding the processes responsible for past events, patterns of change or stability." It is theory "about the nature of man and the causes of history" (1981b:24). For Binford, Schiffer's failure to consider the relationship of general theory to middle-range theory is one of the most objectionable features of his program. The objection includes the following line of reasoning. Without explicit prior consideration of general theory, there is no guarantee that any particular behavioral description generated by behavioral archaeology will be sufficient when judged in terms of that theory. Behavioral descriptions inferred from the archaeological record may simply turn out to be irrelevant to the best means at one's disposal for the explanation of behavior. The description may not refer to any phenomena that theory demands be measured. If theoretically salient phenomena are monitored in the description, it may be in ways that confound variables that theory demands be treated separately. This appears of be at least one aspect of the substance behind Binford's pejorative characterization of Schiffer's program as empiricist, and the charge that it fails to offer a means "of evaluating our archaeological culture or seeking to understand what we want to know in new ways" (Binford 1986:462). Two aspects of this critique are noteworthy. First, it is premised on acceptance of the dichotomy between inference and explanation. Second, and an expectable consequence of the first, despite the fact that it stresses the priority of general theory, it is unaccompanied by any systematic attempt to outline what that theory ought to look like.

The importance and perhaps the ultimate justification of the dichotomy between inference and explanation for Binford is evident in his explicit insistence that "our middle-range theory must be intellectually independent of our general theory". This independence is necessary if giving meaning to the archaeological record is not to become a tautologous exercise (1981b:29, see also Sabloff, et al. 1987:206). Behind this assertion lies the observation that one cannot reason to conclusions that contradict the premises with which one starts. If the premises used in the inference of dynamics from archaeological statics are derived from the same principles that are invoked in the explanation of dynamics, then according to Binford there can be no testing of evaluation of explanations. "Quite literally all our reasoning is 'locked in' by our original premises and observation language" (1981:29). If that observation language is a product of theories about processes responsible for past events and patterns of change, statements about the record become tautologies. An independently developed middle-range theory is supposed to allow archaeology to escape from this circular reasoning. As we shall see below, this position, while superficially plausible, is in fact profoundly misleading.

1.3 Reconstructionism

From this cursory overview, it should be plain that at the heart of both behavioral archaeology and middle-range theory lies the dichotomy between inference and explanation and the attendant notion that behavioral reconstructions are first inferred from the record and then explained. I will refer to this position as reconstructionism. The division of archaeological inference from explanation arises from the fundamental premise of reconstructionism: the theoretical tools one brings to the first part of this enterprise are different from those that are employed in the second. I argue below that there is a grain of truth in this notion. There is a sense in which two different sorts of theory are involved in the production of knowledge from the archaeological record. However, reconstructionist categories confound the distinctions that are necessary for its apprehension.

The reader should note that reconstructionism has been employed elsewhere in the literature to refer to a variety of alleged intellectual sins. Robert Dunnell originally used it to denote, and condemn as scientifically unproductive, any attempt to make inferences about the kinds of past dynamic processes or behavior in which artifacts once participated (1978a, 1978b). Binford uses it to characterize what to him seem objectionable aspects of the work of Schiffer and Richard Gould, in particular the empiricist position that archaeological inference should produce ethnographic descriptions from which laws of human behavior will emerge as empirical generalizations (1986:464). Paradoxically, a careful reading of Dunnell's original formulation makes it clear that it included Binford's position. Despite the potential for confusion, I use the term in a third sense here because it nicely describes the intermediate product of the two-step approach, behavioral reconstructions. In addition my guess is that problems arising from the fundamental premise of reconstructionism, lie behind the disquiet created by "anthropological" archaeology for Dunnell and by Schiffer's work for Binford.

The problems with reconstructionism are effectively exposed in the more precise terminological framework offered by Schiffer. Hence the discussion below is cast in terms of Schiffer's distinction between correlates and transforms, but includes examples intended as contributions to the Binfordian program. I will argue that behavioral archaeology and middle-range theory confound two fundamentally different approaches to the inferential enterprise. These two approaches, which I shall call archaeometry and functional morphology, are each governed by distinct bodies of theory. The archaeometric approach to inference is grounded in the theoretical systems of the natural sciences. The functional morphological approach makes use of these same systems but in addition necessarily involves presumptions or principles, usually hidden, concerning the determinants of human nature and history. In other words, what archaeologists refer to as general theory is a crucial part of archaeological inference based on functional morphology. I therefore devote more of the discussion below to functional morphology.

I hope to show that both archaeometry and functional morphology provide the foundations for behavioral inference; hence both are sources of Schiffer's behavioral correlates. Similarly, both archaeometry and functional morphology underlie inferences concerning site formation processes. Both are sources of Schiffer's transforms. This implies that the distinction between middle-range and general theory and between inference and explanation is a red herring. The development of general theory is necessary if archaeologists are to solve the inferential problems currently discussed under the middle-range theory and behavioral-archaeology rubrics. A second implication is that Schiffer's correlates and transforms are not distinct sets of principles, but are derived from the same two bodies of theory. From a theoretical perspective, the distinction between the two is groundless.

The following discussion illustrates by example how archaeometric and functional morphological principles serve as sources for behavioral correlates and site formation transforms. It will prove useful first to recall a contrast noted by some archaeologists over the past two decades between two sorts of general principles (e.g. Dunnell 1971:30-42, Binford 1978, Gould and Watson 1982). The principles traditionally referred to as empirical generalizations, are based on contemporary observation of phenomena, in this case the conjunction of static, material patterns that potentially may be observed archaeologically, and dynamics, the forces in operation that create patterns. Empirical generalizations are abstract descriptions of correlations between statics and dynamics that have been found to characterize some finite sample of observations. The contrasting class of principles are theoretical laws, deductively derived imaginary constructs, that purport to isolate causal connections between classes of phenomena. The two sets of principles that I am calling archaeometry and functional morphology include both empirical generalizations and laws.

1.3.1 Archaeometry and Behavioral Correlates

Archaeometry is an important source of principles that serve as behavioral correlates. The archaeometric approach to inference deals with the physical and chemical traces left on artifacts or other modified objects by their interactions with certain aspects of the environment in the past. The goal is to infer something of the character of those interactions or the environment in which they took place. The principles that govern the relationships between traces and the forces that produced them, and that make inference possible, range from laws to empirical generalizations.

Where laws are involved, they are derived more or less unaltered from the theoretical systems of the natural sciences. From them in turn are derived models of basic physical, chemical and biological processes that allow links of causal necessity to be forged between physical traces and the processes that produced them. For the most part, applications based on such models are what have traditionally been thought of as archaeometry, largely because until recently the investigators responsible for them have been card-carrying physical scientists. Prominent recent examples of the approach include studies of relict chemical traces in skeletal tissue that, relying upon models developed from isotope chemistry and molecular biology, make possible inferences about components of diet and more generally the kinds of substances ingested by ancient peoples (e.g. Van der Merwe 1982, Aufderheide et al. 1981).

Analogous models of past processes can also be derived from empirical generalizations. Empirically-based models are intended to do the same kinds of things as the law-based models, provide links between statics and dynamics. In general applications based on such models tend to be thought of as archaeology, because the people doing them are trained as archaeologists. Recent examples in this genre include studies of "use wear" patterns on lithics (e.g. Keeley 1980) or patterns of surface damage on bone (e.g. Potts and Shipman 1981) aimed at inferring the kinds of materials with which study objects came in contact in the past and the kinds of motions involved.

Law-based models are clearly preferable. Inferences based upon empirical generalizations are more likely to be wrong. This does not mean, as some archaeologists appear to think (e.g. Gould in Gould and Watson 1982), that inferences grounded in law-derived models are guaranteed to be empirically correct. Both approaches generate disagreement, although empirically based approaches probably generate more of it. It is the contrasting nature of the controversy that is telling. Law-based models generate disagreement over conclusions. However the participants join in a dialogue. For example, Sealy and van der Merwe recently attempted, by examining stable carbon isotope ratios in human bone, to evaluate Parkington's hypothesis that prehistoric groups in the Southwestern Cape, South Africa, wintered on the Atlantic coast and summered in the mountains inland. Food resources available in the two areas are isotopically different. So too, it turns out, are isotope ratios in skeletons from the two regions, suggesting that different populations are being sampled and casting doubt on Parkington's hypothesis. From the resulting exchange (Sealy and van der Merwe 1986, Parkington 1987), there emerges a consensus on areas of ignorance, that is the aspects of the real world that are too poorly known to be included in the model on which inference is based, in this case the need for a better understanding of the biochemical mechanisms by which carbon in food is transformed into carbon in bone collagen where it is measured. There is also agreement on the identification of variables whose causal significance is currently understood and of potential relevance to the model and the inferences arising from it, but whose values are currently unknown. Here the proportion of meat in the diet may affect bone isotope values in bone, confounding differences due to the rest of the diet. Both parties agree on the need and means to control this variable: measure strontium isotope ratios. The controversy is moved forward and participants glimpse the means by which the substantive issues might be resolved. This result is a consequence of the control over variables that theoretical knowledge of causal relationships uniquely offers.

When models are driven by empirical generalizations, the results are less progressive, witness the current controversy over the role of polishes in lithic use wear analysis. Keeley (1980), using an entirely inductive approach, has claimed that contact between flint and different kinds of worked material produces different kinds of polish on the tool's surface. The resulting techniques have been employed to determine stone tool uses. However, the results of a series of blind tests, in which tools used on known materials were analyzed by workers trained in Keeley's approach, suggest that polishes are of no discriminatory significance (Newcomer et al. 1986). In the ensuing exchange (Bamforth 1988, Hurcombe 1988, Newcomer et al. 1988), the parties simply talk past one another. The participants have different notions of what "polish" refers to. This lack of consensus on a framework in which to conduct the discussion is a direct result of the lack of consideration on all sides of the causal mechanisms that might be at work to produce surface modifications. As a result the exchange is largely a restatement of positions colored by rhetorical posturing.

Models based on empirical generalizations sometimes prepare the way for their replacement by law-based inferences. The study of lithic technology in archaeology began with the observation of correlations between the properties of fractures on rocks and the nature of the forces that created them (Grayson 1986). Empirical generalizations about conchoidal fracture have since been superceded by models of fracture mechanics borrowed from physics. Similar deductive models for other kinds of fractures common on working edges of stone tools may eventually replace some of the empirically based models that currently dominate use-wear studies (e.g. Cotterell and Kamminga 1987). Note that the accuracy of empirical generalizations, and the accuracy of the inferences they make possible, rests on their potential conformity with the theoretical systems of the natural sciences. It is on the basis of their potential reliance on models derived from the hard sciences that empirically based models are usefully grouped along with them as part of an archaeometric approach to behavioral correlates.

1.3.2 Functional Morphology and Behavioral Correlates

The functional morphological approach to behavioral correlates attempts to use what as a first approximation I will call the "designed" attributes of artifacts to make inferences about the manner in which they participated in matter-energy flows in past cultural systems. Behavioral correlates may be developed for artifacts at a variety of scales, from discrete objects to assemblages to settlement patterns. Here it is not the actual physical traces of motion or interaction with the environment that are considered as indicators of past dynamics, but rather the characteristics or morphology of artifacts that affect their potential for motion or interaction with the environment during use by humans.

Here too one can distinguish models that serve as behavioral correlates that are based on laws from those generated from empirical generalizations. The empirical generalizations are simply abstract descriptions of ethnographic cases from human groups that happen to be available at present. The descriptions purport to document covariation along a dimension of artifact form and a dimension of behavior. Naroll's

(1962) attempt to establish a relationship between floor area and household size, along with later refinements (Watson 1979), are well known members of the genre. Recent work, cast as a contribution to middle-range theory, on the pithouse-to-pueblo transition in the Southwest offers a more current example. Gilman (1987) finds that among ethnographically sampled groups both pithouses and pueblos are cold-season habitations in a seasonally variable settlement pattern, with pueblos found in groups with more intensive agricultural systems. She uses this generalization to argue that agricultural intensification lies behind the use of pueblos in the Southwest. The inference, like empirically based inferences in the archaeometric approach, is especially suspect for the same reasons. The point is apparently recognized by Gilman since she is at pains to offer independent evidence that intensification in the Southwest actually occurred.

However, as was the case for archaeometry, empirical generalizations can be construed in a more positive light as the starting point for the development of models specifying the causal interactions that underlie ethnographically documented trends and that in turn can be used more reliably in archaeological inference (e.g. Gilman 1987:540, Sabloff et al. 1987:207). Such models typically specify the effects or consequences of the attributes of artifacts that make them more suitable or "adaptive" than others when paired with certain behaviors or uses in certain environmental contexts. It is the specification of those behaviors or uses that is the end result of the inference. Inferred uses are those for which the artifact morphology, given its consequences, is most suited. In other words, the behavior, among a range of alternatives, inferred to have taken place is the one that, in conjunction with the artifact form, generates optimal consequences. Thus when grounded in functional morphology, behavioral correlates are models that purport to exhibit the causal links between artifact form and behavior via performance characteristics of the former. These models often rely on theory from the natural sciences to specify the performance characteristics of artifact form in different behavioral contexts. However, as I argue below, this does not exhaust their need for theoretical underpinning. Two examples may help clarify matters.

In the pithouse-to-pueblo case, one proposed significant morphological dimension of variation is the number of rooms in each sort of structure. Pithouses have single rooms while pueblos have multiple rooms. The parallel behavioral dimension is the number of activities that are performed simultaneously within each sort of structure. The salient consequence that arises from this form-behavior combination is the amount of interference among activities generated by their simultaneous performance (Gilman 1987:557). Multiple-room structures mean less interference and therefore are more suitable for the simultaneous performance of many activities than single-room ones. The latter is one aspect of the behavior inferred to have accompanied the use of multiple-room structures.

Consider a second example. Braun (1983) has recently documented a trend toward decreased thickness in the bodies of ceramic vessels from Illinois during the late Woodland. Using experimental evidence, backed by models derived from mechanics, he demonstrates that ceramics with thinner bodies, other things being equal, tend to have higher resistance to thermal shock and higher thermal conductivity. Given these performance characteristics, thin-bodied ceramics are better suited to cooking methods that involve longer exposure to higher temperatures. When food preparation requires prolonged heating, thinner-walled ceramics fail less frequently and cook more efficiently. Given these use-related consequences for thin-walled ceramics, it is inferred that cooking methods were becoming more intensive during the period.

It is instructive to explore the common structure of these two examples in a more general framework portrayed schematically in Table 1.1. In each case the dimension of morphological variation can be thought of as a dichotomous variable taking one of two mutually exclusive values (e and f), multiple or single-room dwellings in the first example and thin or thick-walled ceramics in the second. Similarly, the dimension of behavioral variation can be represented by a dichotomous variable whose values (c and d) represent the simultaneous performance of many or few activities and intensive or non-intensive cooking. In both cases a model is developed that specifies the consequences, the extent of activity interference and thermal shock resistance, that arise from combinations of behavior and artifact form. The modeled consequences are evaluated or ranked in terms of suitability or goodness. The final step in the argument depends on the covert assertion that this evaluation will lead to the prevalence of the form-behavior combination in the group under study.

		Morphology e	f
Behavior	c	+	-
	d	(-)	(-)

Table 1.1. Evaluation of consequences arising from different combinations of behavior and morphology.

This formalization suggests that two accounts are possible, one synchronic the other diachronic, of the development of consequences and their evaluation on which this approach to inference depends. They are not mutually exclusive. On the synchronic account, the goal is to determine the behavioral significance of the value of the morphological variable, given that a population is known to be characterized by that value. This would require developing the physical consequences of the two alternative behaviors (c and d), for a single value of the morphological variable (e). In the ceramics example, this approach calls for showing why intensive cooking in thin-walled ceramics was better than non-intensive cooking in thin-walled ceramics. In fact, both the ceramic and architectural arguments are structured in the opposite direction, that is they are based on evaluation of consequences associated with the two values of the morphological variable (e and f) in a single behavioral context (c).

In the diachronic account the goal is to infer the behavioral significance of a change from one value of the morphological variable (f) to the alternative (e). This depends upon the development and evaluation of consequences for all four of the possible form-behavior combinations and presumes that one of them, ce in this case, produces the most beneficial consequences (Table 1.1). Both the cases under consideration have a diachronic component. Both involve an archaeologically documented change from one value of the morphological variable to the other: thick to thin ceramic walls and pithouses to pueblos. However, as we have seen, an explicit treatment of half of the necessary evaluations is missing (denoted by parentheses in Table 1.1). In their stead, both studies offer marginal evaluations of behavioral variable values unlinked to artifact morphology. Thus intensive cooking and multiple activity performance (c) are evaluated positively regardless of the artifacts with which they are accomplished. Given these marginal inequalities for behavior and the inequality arising from the evaluation of morphological variation in a single behavioral context, the superiority of a single behavior-form combination (ce) may be deduced. The evaluation of behavioral variability is a function of the wider environmental context. In both studies the relevant contextual change is the emergence of agricultural intensification and high population densities.

We need to examine more closely the kinds of theoretical principles from which a model of the causal links between form and behavior, given the evaluation of consequences in terms of either the synchronic or diachronic accounts sketched above. As we have seen, part of the theory that informs our knowledge of the relationship between form and behavior is borrowed from the natural sciences. In general, as in the examples above, knowledge of the effects of artifact morphology in particular behavioral contexts can be generated from physical principles, but this is only a part of the story. We also require theory that governs the links between the possible consequences of a particular form-behavior combination and the production of its presence in the population under study. By themselves, physical consequences like thermal conductivity or activity interference have absolutely no implications for artifact morphology. What is required is theory that makes possible the ranking of consequences and allows modeling the manner in which this ranking is in turn translated into behavior.

Braun points to the missing link when he writes that form "can be analyzed as a response to the need for a means of effective transmission of forces, an acceptably low cost of manufacture and an acceptably low risk of mechanical failure during use" (1983:111). Considerations of matters like "need" and "acceptability" necessarily involve modelling people and the means by which it is determined what are acceptable effects and what are not. If the differing performance characteristics associated with values of the morphological variable are to have any consequences for the value of the behavioral variable, those characteristics must be in some sense registered and evaluated against some criterion by or for people. The evaluation must in turn lead to adjustments in the value of the morphological variable. Inference therefore requires theory to model the mechanisms involved in evaluation and consequent adjustments. and the manner in which the entire process is set in motion by changes in salient aspects of the environment. The principles from which such models are built are not the laws of physics. Rather they must be laws governing the construction and behavior of organisms. Such principles are precisely the laws of human nature and history that comprise what reconstructionism refers to as general theory. The central dogma of reconstructionism is the proposition that general theory must not be a part of archaeological inference. Yet clearly general theory is crucial to the morphological approach to inference.

1.3.3 Archaeometry and Formation Processes

Just as behavioral correlates allegedly permit the inference of motion or behavior from artifacts, in the Schifferian model, the principles governing formation processes, n-transforms and c-transforms, make possible inferences concerning the dynamics responsible for the formation of deposits that constitute the archaeological record and the depositional histories of their constituents. As we have seen, these processes must be reconstructed with an eye to either removing the distortions they caused or, where that is not possible, eliminating the deposits themselves from further consideration as evidence of human behavior. Inferences concerning site formation processes can be grouped under the same two approaches that emerged from our consideration of behavioral correlates. One can distinguish an archaeometric approach based, in the last analysis, upon the theoretical systems of the natural sciences, and a functional morphological approach based upon both natural science and principles governing the behavior of humans.

The archaeometric approach to site formation transforms focuses on the physical and chemical traces left on deposits or their contents by the forces that created them. The goal is to infer the character of those forces and the contexts in which they operated. Again, models derived from laws and empirical generalizations may be distinguished. Characteristic of law-grounded inferences of non-cultural formation processes is the use of grain size and structural attributes of sediments, in conjunction with physical principles organized in sedimentology and hydrology, as a key to the manner in which they were deposited (e.g. Stein 1985). Thus for example by such means fine-grained sediments that exhibit laminations may be inferred to have been deposited by slow-moving water. Archaeometric approaches can also be based on empirical generalizations, for example Binford's (1981b:249-278) arguments that Olduvai Gorge faunal assemblages are transported and ravaged by carnivores, based on similarities in anatomical part frequencies to assemblages accumulated by modern carnivores.

Archaeometric inferences of cultural formation processes often proceed via an argument by subtraction (e.g. Stein 1985, Binford 1981b:246), where an attempt is made to account for characteristics of a deposit entirely in terms of non-cultural formation processes, after which the residuum is attributed to human behavior. Although they are seldom made explicit (but see Meltzer 1984), similar kinds of arguments lie behind the inference that humans removed materials from their places of natural occurrence in the environment, which have been identified through the use of techniques like trace element analysis or petrography. Archaeometric models lead not only to the identification of hominids as the agents of deposition but also potentially to more detailed inferences about the character of human behavior. For example fracture mechanics guarantee that flakes and the cores from which they were struck or ceramic sherds originally from the same vessel can be uniquely reassembled, making possible inferences about the movements the fragments underwent before final deposition (e.g. Schiffer 1987:285).

1.3.4 Functional Morphology and Formation Processes

A functional morphological approach to the development of principles governing site formation processes attempts to use the attributes of deposits and their contents as evidence for the manner or behavioral context in which they were created. Paralleling the morphological approach to behavioral correlates, interest focuses on the characteristics of deposits or deposited artifacts, that is refuse, that potentially affect matter-energy flows in human social systems. Once again models employed as cultural transforms may be based on empirical generalizations or laws. Empirical generalizations describing ethnographically observed correlations between artifact morphology and disposal behavior comprise much of the body of theory Schiffer refers to as c-transforms. The following are typical. As site size increases, more artifacts will be deposited as secondary refuse, that is away from its location of use (Schiffer 1972:162, 1987:22). Primary refuse, that is artifacts that enter the archaeological record at their place of use, will be comprised of small objects (Schiffer 1983:679).

As was the case with behavioral correlates, generalizations can be viewed charitably as starting points for the elaboration of causal principles that might underlie them. Functional morphological models for cultural formation processes that are derived from theoretical principles have the same two-part logical form we have seen in our consideration of behavioral correlates. First a model of the effects or consequences of the attributes of refuse in a range of behavioral contexts is developed. Then assumptions about human nature are imported into the analysis, usually in a covert fashion, that allow the ranking of consequences generated. This yields a predicted association between form and behavior. The inferential argument proceeds as before.

Binford's attempts to build middle-range theory for the behavioral contexts responsible for the differential disposal of anatomical parts can be seen in this light (1987:452-455). Binford wants to infer the kinds of behavioral contexts among hunter-gatherers in which disposal of faunal remains results in an assemblage dominated by heads and feet. Unsatisfied with simple empirical generalization to the effect that such assemblages come from hunting camps, he seeks to elucidate the causal interactions involved.The proposed model includes a range of behaviors described in two dimensions, the variable distances that meat must be transported from the kill site to residential camp and the removal of the heads and feet. The corresponding set of consequences, measured in terms of energy expenditure, scales with these behavioral possibilities.

Energy savings are greatest when distance is great and anatomical parts with high bone-meat ratios are discarded before transport. If less energy expenditure is better, then the optimum context of behavior is to remove the heads and feet when the kill site is far from the residential camp. That is the inferred behavior. Although the consequences can be generated and elaborated with an elementary knowledge of mammal anatomy and energetics, no attention is paid to the theory underpinning the ranking of the consequences and the manner in which these in turn influence human behavior. Once again there is a crucial role for general theory concerning the behavior of humans in what for Binford is an exercise in middle-range theory and for Schiffer would be the development of c-transforms.

1.4 The Defects of Reconstructionism

At the outset of the discussion of reconstructionism, I noted that there is a sense in which the two different kinds of theory are involved in the production of knowledge from the archaeological record. It should now be evident just what that sense is. On the one hand, there are principles of the physical sciences that power archaeometry and make possible the inference of object-environment interactions from their physical traces. On the other hand, there is a set of principles that governs the construction and behavior of humans. This is general theory that can be used, often in conjunction with models drawn from the physical sciences of the effects of artifact form and behavior in certain environmental contexts, to infer behavior patterns. These distinctions offer the basis for a more concise summary of just how the reconstructionist account of the production of archaeological knowledge is defective. I begin with Schiffer's version of reconstructionism and then turn to Binford's. Binford's position proves somewhat less problematic than Schiffer's. Portions of the Binfordian critique of Schiffer's position do point to real defects. However their significance is misconstrued because of Binford's own brand of reconstructionism.

A first problematic aspect of Schiffer's account is the distinction between c and n-transforms and the attendant notion that these separate bodies of theory make possible inference concerning cultural and natural formation processes respectively. While the theoretical systems of the natural sciences uniquely ground inferences concerning natural formation processes, they also figure importantly in inferences concerning cultural ones. The point has recently been recognized by Stein regarding inferences concerning the agents responsible for deposits (1987:3/5). The above discussion demonstrates the more general applicability of the archaeometric approach to cultural formation processes.

The higher-level distinction between behavioral correlates and c-transforms is equally problematic and for similar reasons. The same two bodies of theory are used in the construction of both correlates and transforms. Models linking the characteristics of artifacts on the one hand and refuse on the other to behavior draw on both the theoretical systems of the natural sciences (archaeometry) and principles concerning human behavior (functional morphology). The notion that correlates and c-transforms are constructed on separate theoretical foundations is false. This result should not be surprising. After all, refuse and the deposits in which it occurs are themselves merely one sort of artifact. Thus transforms, when used to infer cultural formation processes, are revealed as merely a subset of behavioral correlates, behavioral correlates for one type of artifact: garbage. This same observation, that deposits created by humans and refuse are themselves artifacts, lies behind Binford's objection (e.g. 1981a:200) to Schiffer's insistence that the archaeological record offers a view of behavior-artifact interactions in on-going social systems that has been distorted by cultural formation processes.

Schiffer's position on distortion is merely a symptom of the misleading correlate-transform dichotomy, that is where the real theoretical defect lies. It is true that explaining the archaeological record requires models of behavior-artifact interactions before and after artifacts have become refuse. In other words, it is helpful to make a distinction between artifact use and disposal, and to insist that production of archaeological knowledge requires modelling both. But the distinction is a phenomenological one. That Schiffer has mistaken it for a theoretical one is in large part due to his empiricist approach to theory construction. For Schiffer, theory is comprised of empirical generalizations, abstract descriptions of phenomena (e.g. 1983:670, 1987:22). Under this view, what unites theory into a coherent whole is the kind of phenomenon being described. It is as if Newton had decided it necessary to craft separate bodies of theory governing falling apples and falling cannon balls.

Schiffer's attachment to empirical generalizations also leads him to lump the archaeometric and functional morphological approaches to inference in the same package, and point to the former as paradigm cases (e.g. 1976:13). This allows him to discuss the size sorting of sediments in fluid media and size-sorting of artifacts during their disposal by people in the same framework, as if the causal principles behind each were the same (1983). Reconstructionism's failure to distinguish archaeometry from functional morphology hinders recognition of the central role of general theory in the functional-morphological approach to archaeological inference.

The issue of empirical generalizations surfaces in Binford's critique of Schiffer as well. Binford tries to contrast his version of middle-range theory, which allegedly seeks the organizational framework within which behavior is executed, with behavioral archaeology's search for correlates of discrete aspects of behavior (1981a:201, 1987:452-453). Judging from his examples, at the heart of the contrast is Binford's realization that the link between behavior and material remains, especially when discussed in the rubric of functional morphology, is context sensitive. The point emphasizes the extent to which accurate inference depends upon understanding the interactions between variables in a causal framework. Returning to the anatomical parts discussed earlier, a faunal assemblage dominated by heads and feet does not invariably guarantee a hunting camp. The inference depends among other things on the distance of the kill site from a residential camp. If the two are close, there may be no point in severing the heads and feet before returning home. Indeed Binford in this example has gone a bit further to elucidating the causal variables involved in leaving the heads and feet behind. But not far enough. As we have seen there is no attempt to offer a causal treatment of the ranking of energetic consequences of behavioral variation and the adoption of one variant on the basis of that ranking.

Yet the intuition remains that "well supported conclusions about past phenomena are requisites for attempts at explanation", that "one does not try to explain something unless it has occurred" (Sullivan 1978:184-185). These statements, on which reconstructionism is an elaboration, are trivially true. Hence the attraction of reconstructionism. But they are also profoundly misleading. They are true once one has specified a frame of reference or theoretical system within which phenomena can be individuated and classified. Without that specification they are nonsense. An example from evolutionary biology is instructive. It is clear that an explanation of differences in speciation rates between two monophyletic groups presupposes that speciation events occurred and the rates of occurrence were actually different (Vrba 1983). On the other hand, before 1859 speciation was a non-event for most biologists, and it has only been with renewed interest in macro-evolutionary theory over the past decade that differences in speciation rates between monophyletic groups have become "facts" available for observation. What is missing from the reconstructionist position is an appreciation of the fact that the theoretical system in terms of which an explanation is cast is also the theoretical system that allows the individuation of phenomena in the first place.

The point is especially easy to forget in an archaeological context because behavioral transactions do seem somehow non-problematic, at least in comparison to the archaeological record. The illusion that behavior is transparent derives from the fact that there already exist conceptual frameworks that can make sense out of it. Two related, ready-made frameworks are available to archaeologists, "common sense", that is the cultural conventions that we use to navigate our own world, and sociocultural anthropology, an elaboration of common sense to make sense of strangers (Dunnell 1982). There is no common sense or anthropology about the archaeological record, and there is very little about the relationship between artifact morphology and behavior. Thus the challenge appears to be to wring behavior from artifacts. Once this has been accomplished, artifacts cease to be puzzling. It therefore appears that the only task for archaeological theory is the reconstruction of behavior.

This situation has lead to bizarre conclusions. Among them is Binford's requirement that the observation language used for the archaeological record must be independent of theory about past events and processes of change. This is simply a restatement in an archaeological context of outdated positivist epistemology. It may be the contrast between the meaningfulness of behavioral transactions and the muteness of the archaeological record that lends superficial plausibility to this resurrection of a long discredited philosophical position. There can be no theory-free observation language, a notion that Binford himself accepts in other contexts (e.g. 1982). There simply is no escape from the epistemological situation that Binford fears will render interpretations of the archaeological record tautologies. Richard Lewontin has described the dilemma as follows.

> It is not always appreciated that the problem of theory building is a constant interaction between constructing laws and finding an appropriate set of descriptive state variables such that laws can be constructed. We cannot go out and describe the world in any old way and sit back and demand an explanatory and predictive theory be built on that description (Lewontin 1974a:8).

The "circularity" from which Binford hopes middle range theory will allow escape is unavoidable.

Reconstructionism will hinder the development of a successful scientific archaeology. Its denial that general theory is an integral part of the inference of behavioral reconstructions made under functional morphology has two principle consequences. First, it insures that the principles that necessarily are employed in reconstructions remain covert and renders them immune from explicit testing and evaluation. Thus reconstructionism precludes the theoretical development that is crucial to scientific progress. The second consequence is equally damaging. The neglect of theory means that models for inference will remain fundamentally incomplete. The mechanisms that are hypothesized to be at work in a given situation will be only partially explicated. This precludes the full development of model consequences on the basis of which models may be evaluated. It therefore handicaps efforts to determine whether hypotheses are wrong.

So far I have treated the archaeometric and functional morphological approaches to inference as co-equal. It is now time to abandon this expository fiction and recognize that general theory sets the agenda for archaeometry. Archaeology is fundamentally about the description and explanation of human history from material remains. It is not merely "artifact physics" (DeBoer and Lathrap 1979). Artifacts possess a very large number of properties that might be grist for the archaeometric mill by virtue of being traces of past dynamics of one sort or another. However, not all past dynamics are relevant to the inference of historical processes. General theory provides the basic assumptions about how human history works that determine which aspects of the past are considered historically important and therefore about which it is worth making or testing inferences in an archaeometric framework.

From this wider perspective, archaeological inference is a much larger enterprise. Theory specifies entities, their salient properties and the processes in which they figure. From theory models are constructed that attempt to work out the relations between phenomena that might be anticipated on the basis of various assumptions about the theoretical processes at work in a given case. When models are matched against facts cast in theoretically appropriate terms, one can then infer something about the causal mechanisms that produced them. This is the more general sense in which inference is understood in the rest of science (e.g. Platt 1964, Lewontin 1980). In other words, inference *is* explanation.

1.5 Toward a Framework for General Theory

In the preceding section I have argued that what archaeologists know as fundamental or general theory is crucial to the production of archaeological knowledge. It remains to be seen what sort of general theory archaeologists should attempt to develop. The answer depends upon what sort of knowledge one wants archaeology to produce. Within a scholarly setting, two options can be distinguished empirically, on the basis of contrasting patterning in the temporal distribution of their knowledge products.

The first, natural-scientific knowledge, is cumulative and progressive at both an empirical and theoretical level. At an empirical level, progress consists of increases in the ability to make predictions that, when matched against measurements of phenomena, will not surprise us (Hesse 1978, Dunnell 1978, 1982). Increases in the quantity and quality of this pragmatic knowledge are to some extent independent of the theoretical systems in which it is embedded. Rockets reach the moon whether their courses are computed in a Newtonian or relativistic framework. Although Newtonian trajectories are less accurate, they work.

At a theoretical level, progress results from testing theoretical systems over the long term using what Hesse calls the "pragmatic criterion" and Dunnell refers to as "performance standards": new theoretical complexes are adopted if they increase pragmatic knowledge. Especially noteworthy is the character of the resulting relationship between older theoretical systems and the pragmatically superior systems that replace them. Once a successful scientific tradition has been developed, when theoretical renovation becomes necessary, older frameworks often turn out to be special cases of new ones. Seen in the light of its successor, older theory still offers an acceptable account of some subset the phenomena covered by new theory. The subset is defined in terms of a limited range of parameter values or levels of organization (e.g. Wimsatt 1981). Current theoretical upheavals in evolutionary biology offer a case in point. It is argued by some that natural selection may operate at many levels in the biological hierarchy, that is on genes, organisms, populations and species, and not just at the level of individual organisms, as insisted by the New Synthesis (e.g. Vrba and Eldredge 1984). From the emerging perspective, the Synthesis of the 1930's offered a useful and essentially correct theoretical account of selection within populations, but erred in ignoring other levels of organization. The Synthesis emerges as incomplete and overextended, but it is not wholly repudiated.

The temporal patterning in the empirical and theoretical products of a second kind of knowledge, typically produced by the social sciences, offers a stark contrast. At the empirical level, successive conceptual frameworks do not appear to result in increased control of the phenomena studied (Gergen 1986). When theoretical renovations occur, they are traumatic episodes, characterized by the rejection of the earlier theoretical system and its replacement by an incompatible new one. It is paradoxical that this characterization of temporal patterning in the products of social science resembles Kuhn's (1972) portrayal of "revolutions" in natural science. That Kuhn's work is more applicable to the former case than the latter is suggested by the enormous popularity it enjoys in the social sciences (e.g. Fiske and Schweder 1986:379-384) and in archaeology (reviewed in Meltzer 1979). Thus the successive replacement of one incommensurate theoretical paradigm by another ought to be familiar to archaeologists. Sociocultural anthropology offers a prime example of it. The field is littered with incompatible frameworks, some wholly abandoned, others still vying for hegemony. In fact, since the failure of the New Archaeology to deliver a progressive scientific research program, the very same intellectual fads that compete for dominance in sociocultural anthropology have begun to appear in archaeology where they are collectively labeled "post-processual archaeology". Prominent examples include a variety of marxisms, most conspicuous among them structural marxism (e.g. Miller and Tilley 1984) and critical theory (e.g. Leone et al. 1987), along with less diluted symbolic approaches (e.g. Hodder 1986).

If one finds the prospect of archaeology's transformation into a progressive producer of knowledge on the natural science model appealing, archaeological theory should be cast in the natural science mold. In the furtherance of that goal, it would be helpful to know just what it is about natural-science theory that renders the research traditions that it underpins progressive, and conversely what it is about social-science theory that renders its products ephemeral.

1.5.1 The Manifest and Scientific Images

I begin with a distinction borrowed from philosopher Wilfrid Sellars (1963). Sellars describes two different metaphysical frameworks in which the world, including the people in it, may be understood: the manifest image and the scientific image. In the manifest image, phenomena are understood under the category of persons. Processes are conceived as the actions of persons behind which lie motivations and intentions. These, in turn, are interpreted expressions of character or essence. Causation is therefore teleological: things happen according to a plan, for a purpose, to achieve a goal. This is the metaphysical framework in which people the world over have understood themselves and metaphorically much of the world around them. In other words, it is the framework of common sense, what sociocultural anthropologists refer to as "culture".

The scientific image of the world has abandoned the language of person description as an acceptable account of the kinds of entities and processes that exist in the world. Instead phenomena are to be understood as complex physical systems. Processes are sequences of effects and antecedent causes. Causation is therefore not teleological, but mechanistic. Relative to the manifest image, the scientific image is a recent development, dating to the sixteenth century. Since then the scientific image has become the foundation for successful natural-science research programs in physics, chemistry and biology.

Despite the fact that the name suggests otherwise, social science is built on the metaphysics of the manifest image. Social-science theories variously understand individuals or historical processes in terms of character and purpose. Even frameworks that minimize the importance of individual persons' intentions use the manifest image as a key to understanding their alleged determinants (Rosenburg 1980). Different social-science theories can be distinguished by the fact that each privileges one or a small number of characterizations of human nature chosen from those found in the common culture of their practitioners.

One can distinguish two classes of social-science theory by the manner in which they incorporate the manifest image. The first is based on some characterization of human nature, a small set of dispositions or behavioral goals alleged to underlie human behavior in all times and places. Marvin Harris' cultural materialism is grounded in this way (1979). His list of four "bio-psychological" constants includes the needs for affection, food and sex, along with the propensity to achieve these goal states with minimum energy expenditure. Other authors offer sharply contrasting dispositions or goals, for example the tendency to conserve order and meaning in cultural experience (e.g. Sahlins 1976). The second approach recognizes that human goals and dispositions may be historically variable among individuals, that is human nature may vary. However, to explain this variability, it relocates plans and goals in history itself. History is rendered as a set of societal or economic types, each determining the dispositions of member individuals. Neo-evolutionism's bands, tribes, chiefdoms and states are one obvious example (Dunnell 1980:40-46, Leonard and Jones 1987). Marxism's lineage, Asiatic, feudal and capitalist modes of production offer another (Wenke 1981:92-99, Bloch 1983:32-43). The societal types are linked together in a pseudo-historical sequence leading to the realization of a class, societal or historical goal, for example social complexity, efficiency of energy capture, or dialectical synthesis.

The differences outlined above between temporal patterning in the knowledge products of social science and natural science can be attributed to the fact that social science theories are grounded in the manifest image. This use of the manifest image helps insure that the results of social science will appear empirically inadequate and theoretically inconsistent when tracked over time. Empirical inadequacy is evident in the difficulties social science theories have handling change. Theories that trade in an invariant human nature are necessarily static. They are premised on denial of what has undoubtedly occurred: the referents of the dispositions invoked as part of human nature have changed over historical time. Hominid species have evolved both genetically and culturally. Attempts to accommodate the possibility of change in the nature of human individuals rely on programed development through a series of stages, often guided by a final cause. Use of the manifest image thus leads to a mystical interpretation of causality in order to accommodate change. The assumptions on which social-science theory is built appear to lead positions about historical causality that we have good reason, based in natural science, to suspect are false.

Theoretical inconsistency over time arises from the fact that both common sense and social-science theory are derived from the manifest image. They are metaphysically compatible. As a result, social-science theories are particularly liable to be influenced by the contents of common sense. Common sense is historically and socially variable. This is the lesson of anthropology. Since the characterizations of human nature employed by social science are derived from common sense, they are historically variable too. When culture changes so will its social science theories. As might be expected on this account, the primary temporal trend in anthropology over the past twenty years has been an increase in the number of competing interpretive schools as scholars have been drawn from more diverse cultural backgrounds. The connection with common sense insures that social-science theory is retained or discarded for reasons other than Hesse's performance criterion, because it coheres with a popular order of values, or because it is compatible with culturally sanctioned images of the good (Hesse 1978:12, Gergen 1986:151). Natural-science theory is relatively insulated against similar effects. It is developed in a tradition that is independent of common sense. This independence is fostered by the fact that it rejects the person-based metaphysics of the manifest image in favor of a mechanistic view of process. As a result, empirical utility has less competition from other means of sorting among theoretical notions.

The theoretical notions comprising common sense are innumerable, largely implicit, unanalyzed, and contradictory. The causes of their existence are obscure, buried in an largely undocumented past. On the other hand, natural-science theory is comprised of self-contained sets of explicitly posited entities, their characteristics and sets of laws governing their interactions. All three are organized into inferential complexes, in such a way that their logical connections are explicit (Dunnell 1982, Hull 1983, Quine 1960:22). The limited and explicit nature of natural-science theory renders it susceptible to evaluation. When a recalcitrant experience or apparent falsification of an hypothesis occurs there is a reasonable possibility that, over the long term, the research community will be able to determine what aspects of theory, assumptions, or measurements that went into it are incorrect. Social science theories do admit a certain amount of independent axiomatic elaboration. However, since their terms cannot be divorced from the rest of common sense, the possibilities in this direction are limited. Discourse is always at risk of being dragged back into the larger contradictory repertoire of person descriptions from which the local characterization of human nature was derived. Hence when recalcitrant experiences occur in social science, it is nearly impossible to isolate which theoretical component of an hypothesis is wanting.

Despite the fact that competing social-science theories can be seen as the outcome of attempts to privilege and organize different subsets of common sense, common sense remains the more powerful sense-making system (Dunnell 1982, Symons 1987). This is because individuals use common sense to navigate the world around them. Over the short term, common sense allows individuals to predict and hence cope with a wide variety of phenomena in the natural and social environment. It therefore has empirical consequences, consequences that can involve the survival and reproduction of its users. Social-science theory operates under no such constraints.

1.5.2 Essentialism

Dunnell (1982) has recently offered a similar appraisal of the knowledge products of social science, although his diagnosis of the factors responsible for it differs. It is worth briefly considering a portion of his argument because it will help pinpoint a final metaphysical infirmity in the manifest image. Following Mayr (1959), Dunnell suggests that there are two kinds of science: historical and non-historical science. The paradigm cases of non-historical science are physics and chemistry. There is only one successful historical science: evolutionary biology. The two kinds of science each have their own metaphysical foundations. Essentialism underpins non-historical science, along with common sense and social science. Essentialist approaches work where the phenomena under study do not change. "Population thinking", on the other hand, provides the foundation of evolutionary biology. It uniquely can handle change. Mayr argued that a necessary condition for the existence of a scientific biology was abandonment of essentialism, and the substitution of population thinking in its place. Darwin was the architect of this change. Under Darwin's theory variation was no longer seen as the result of forces interfering with the expression of a species essence, but as a thing in itself that, along with natural selection, is the cause of evolution (cf. Lewontin 1974b:5). In a similar vein, Dunnell sees the essentialism of common sense and social science as the source of their incompatibility with a scientific archaeology. The abandonment of the essentialist metaphysic is a necessary condition for the creation of a scientific archaeology. An appreciation of the issue requires understanding just what is meant by essentialism.

One can distinguish two brands of essentialism. The first is Aristotle's "Natural State Model". It supplies a means of handling diversity among phenomena. Aristotle made a fundamental distinction between those states that are natural to an object and those that are not. Non-natural states are produced by subjecting the object in question to an interfering force (Sober 1980:360-361). Variation is therefore rendered as deviation from what is natural. Typical examples are drawn from physics. In Aristotle's physics, the natural state of sublunar objects was to be located at the center of the earth. In Newtonian physics, the natural state of all objects is to continue to remain at rest or in uniform motion.

A weaker form of essentialism is implied by the notion that objects have necessary properties -- essences -- that cause them to be the way they are or to behave in certain ways (Sober 1984:164). The periodic table of elements familiar from high-school chemistry offers an example. The fact that nitrogen has atomic number 14 is a necessary property of the element that causes it to have certain kinds of interactions with other elements. Similar conceptions are found in physics. All bodies have a mass. All electrons have negative charges. Essences in this sense, whether conceived as continuously or discretely varying, are timeless properties that figure in scientific laws governing the behavior of phenomena.

If either kind of essentialism is to be scientifically successful, then one must correctly specify the kinds of objects that have essences and what their essences are. Neither task is trivial. Aristotle and Newton agreed that physical objects had essences on the natural state model, but not on what they were. The first progressive research program in chemistry was founded on correct identification of what kinds of things have essences of the weaker sort: the realization that individual elements (e.g. oxygen, nitrogen) do, but "air" does not.

I argue that what was crucial to the Darwinian revolution was not the abandonment of essentialism, but a re-identification of the kind of phenomena to which it was to be applied (Sober 1980, 1984:155-169). Evolutionary theory has abandoned the notion that individual organisms have a species essence that is unchanging. The notion of a "human nature" is merely a special case. Essential, causally efficacious properties are now conceived to belong to a different sort of object: populations of organisms sharing genetic information in time and space. At this new level, essentialism of both sorts is alive and well in evolutionary theory. The Hardy-Weinberg law describes what happens to gene and genotype frequencies in a panmictic Mendelian populations when no forces interfere. It offers a natural state model of Mendelian populations. The weaker form of essentialism can be found in the terms of other evolutionary laws. Evolutionary theory is about necessary properties of objects that cause them to behave in certain ways. Populations are predators or prey, specialists or generalists, r or k-selected and so forth. When the essential properties of other kinds of objects are considered, it is always in terms of the dynamics of populations. Genes, genotypes and phenotypes are selectively advantageous, disadvantageous or neutral, characteristics only conceivable in a population context. The selection coefficients attached to them are formally analogous to the mass attached to a Newtonian body.

On this construction, our single example of an historical science proves to be essentialist. This would suggest that in fact there is only one kind of science. This result should hardly be surprising. The entities, their properties and the processes in which they participate, postulated in natural-science theory are universal. Theory applies to all phenomena of a specified sort, without spatio-temporal specification. It can be expected to work irrespective of time or place. Evolutionary theory is no different. What Mayr and Dunnell deride as essentialism is the outcome of incorrect identification of what kinds of objects have eternal properties. The problem with "essentialist approaches" to historical phenomena is not that they are essentialist, but they locate causally efficacious essences in the wrong place. The triumph of population thinking is its location of these properties at the population level, its "commitment to the methodological fruitfulness of constructing theories whose parameters apply to populations" (Sober 1984:168).

It is here that we glimpse another infirmity of the manifest image, its tendency to assume that causally important, necessary properties inhere in phenomena that appear to be discrete objects at the scale of human observation. It may be no accident that a successful scientific research program was first established in an area where this condition was most closely approximated: Newtonian mechanics. Thus one suspects that a final reason for the failure of the social sciences, or any conceptual framework based in the manifest image, to deliver a progressive research program lies in their failure to conceive human history in terms of the kinds of objects that are subject to causal invariances.

1.6 Implications for Archaeology

The description offered above of the epistemological status of social-science knowledge claims should have a familiar ring to archaeologists. Similar positions concerning the epistemological status of archaeological inquiry have been developed and enthusiastically embraced by post-processual archaeologists peddling a variety of trendy approaches, among them Marxism, structural-Marxism, critical theory, hermeneutics and mongrel permutations of these. Elements of the post-processual critique are variable. They range from outright denial that anything that might be called secure, objective knowledge of the past is possible (Hodder 1986:16,1987) to privileging explanations derived from a particular teleological view of history (Leone and Palkovich 1983, Wylie 1985). The two positions appear in the same work (Leone et al. 1987). Despite logical lapses, post-processual archaeologists agree that they have buried the notion of a progressive, scientific archaeology once and for all. I hope that the preceding section shows in precisely what sense these conclusions are correct. They are correct only if one accepts the premise of the argument, that all understandings of the human past should be grounded in a conception of change as meaningful human action, that is in the manifest image. I also hope to have shown that it is not only possible to reject this premise, but why it might be desirable to do so.

Where can one turn for a theoretical system in the scientific image with which to begin to make sense of the archaeological record? The answer I attempt to explore in what follows is evolutionary theory in the Darwinian mold. Evolutionary theory looks promising for a number of reasons. Some of these will emerge in the next chapter. One of them is relevant in the context of the preceding discussion. As Mayr and Dunnell have pointed out, Darwinian theory provided the foundation for the first and only successful scientific research program for historical phenomena ever developed. It is instructive to note that the theoretical systems for the history of life that Darwinism replaced were themselves built from the manifest image. This is true of religious accounts that relied on the intentions of a creator. It is also true of secular systems like those of Lamark, Owen and Chambers (Hull 1983). Lamarck's scheme offers a good example because it incorporated both programmed development and individual motivation. History was driven by two orthogonal forces. The first was general striving for progress that infused all organisms, creating greater complexity in successive generations and propelling them up a predetermined tree of life. The second was the ability of organisms to alter their habits in small ways in response to their own unique needs, determining which branches on the tree were taken (Hull 1982). The person metaphor figures in these constructions. Its effects were similar to those discussed above in connection with human history. As long as organisms were conceived in the manifest image, natural historical explanations rested entirely on *a priori* notions, driven by common sense, about the intentions of organisms or their creator or plans for the history of life. In this context, Darwin's account of evolution by natural selection was unique. It offered a wholly mechanistic explanation for the history of life and in so doing altered the kinds of objects that might have causally efficacious, eternal properties. The success of evolutionary theory in this context, suggests that it may offer a solution to a similar problem in a related one.

Chapter 2

The Structure of Evolutionary Theory

2 Introduction

I begin this chapter with an outline of the overall structure of neo-Darwinian theory as it has emerged from the Synthesis during the middle years of this century. Neo-Darwinian theory is a theory of forces comprised of two sorts of laws, consequence and source laws, which purport to describe the dynamics of the distribution of genetic information in time and space and the conditions that bring those dynamics into existence. The complete evolutionary explanation of biological phenomena requires both. A necessary condition for the successful application of an evolutionary approach to the archaeological record is the development of both source and consequence laws for human behavior. The notion that evolutionary theory is a theory of forces allows a more precise understanding of the deficits and unhealthy consequences of the current state of archaeological theorizing. I suggest how some of the current archaeological literature might be construed as a contribution to the construction of source laws. However, there is no parallel attempt to develop consequence laws to describe how forces work, which the example of evolutionary biology suggests are required for the development of a successful research program.

This raises the question of what a sufficient evolutionary theory of forces for human behavior might look like. Much of the recent work in human sociobiology is based on the claim that a complete theory already exists and can be imported without extensions into the analysis of human behavior. That theory is neo-Darwinism. I examine this claim in the light of the structure of evolutionary theory and find it wanting. I argue that, while neo-Darwinian theory offers an essential starting place for an evolutionary treatment of human behavior, extensions to it are necessary to accommodate the novel forces introduced by the ability of individuals to engage in individual and especially social learning. During the past decade a group of workers with backgrounds in evolutionary ecology and population genetics have begun the task of supplying the needed extensions: explicit descriptions of the forces that operate in cultural evolution and a link between them and neo-Darwinian processes. I think it likely that the resulting coevolutionary or dual-inheritance approach will provide the foundation for a progressive evolutionary research program in archaeology.

2.1 Evolutionary Theory as a Theory of Forces

In Chapter 1, I argued that the claim that there are two kinds of science, one essentialist the other non-essentialist, was, in the last analysis, mistaken. In this section, I pursue this argument to exhibit the commonalities of structure between neo-Darwinian evolutionary theory, as it has been developed in biology since the Synthesis, and what has been taken to be the paradigm case of essentialist theory, physics. The resulting framework should help clarify the explanatory role of much existing archaeological theory in an evolutionary context. It will also lead to a more precise identification of the major lacuna in current theoretical work undertaken by archaeologists.

Elliot Sober (1984) suggests that the key to understanding how neo-Darwinian theory works is to realize that it is a theory of forces. Physics offers the paradigm case of a theory of forces and thus offers a good place to begin our examination of what is involved. At the foundation of a theory of forces is a law that describes a zero-force state, that is what happens to the system being modeled when no forces operate upon it. Zero-force laws are important because they specify precisely what it is that, in the absence of perturbations, does not change. In Newtonian mechanics, the property of objects subject to no forces is constant velocity. In Aristotle's physics the zero-force state was rest at the center of the earth (Sober 1984:31-32). As this example suggests, specification of a scientifically fruitful zero-force state is a non-trivial matter. In a world dominated by gravity, where constant velocity appears to require work, Newton's zero-force state is wholly counterintuitive. Zero-force laws play a key role in the individuation of phenomena, indicating the nature of the system under study, just what it is that needs to be explained and when forces must be invoked to do the explaining.

Once a zero-force law has been posited, one can proceed to the enumeration of different forces and description of the processes whereby they operate. Each force represents a possible cause of system change. Newtonian mechanics recognized a single force, gravity. Modern physics recognizes four. Sober distinguishes two sorts of laws about forces: source laws and consequence laws (1984:50-51). Both are crucial to the conduct of inquiry, but they have different roles. Source laws specify the conditions under which a force can be expected to come into existence. An example from Newtonian mechanics is the law of gravitation, stating that when two bodies of a given mass are separated by a given distance there will be a gravitational force proportional to the square of the inverse distance between them. Consequence laws, on the other hand, stipulate how, once a force exists, it impinges upon the system. They describe the implications of the operation of the force for system dynamics. Hence consequence laws necessarily contain some representation of the manner in which forces work. The classical example here is "F=ma", which says what happens to an object when it is subject to a force. Note that no mention is made here of the conditions that produced the force. Instead the emphasis is on the operation of the force, once it exists, and its effects on the behavior of a system. Because consequence laws allow predictions about system dynamics, they make possible inferences concerning the character of forces operating on a system, based on observation of its dynamic behavior. Finally, a fully developed theory of forces contains not only single force laws, but also laws that describe what happens when different forces operate in concert. Source and consequence laws work together to provide predictions. Source laws tell us what forces we can expect in a given set of circumstances, and perhaps even permit estimates of their magnitudes. Consequence laws describe how forces work and thus can be used to predict system trajectories that result from their operation.

How does neo-Darwinian theory fit into this framework? We can begin with the zero-force law of evolutionary theory. It posits that, in the absence of forces, there will be no change in the frequency of genetic variants from one generation to the next within an infinitely large group of randomly mating organisms. For diploid organisms, this equilibrium condition is usually described by the Hardy-Weinberg law, which relates gene to genotype frequencies under random mating using the rules of probability. However, a more fundamental construction is possible, covering both haploid and diploid genetic systems. The fact that gene frequencies are stable in the absence of interfering forces flows ultimately from the facts that genes usually make faithful copies of themselves and that the copying process is fair (Sober 1984:36, Kimura 1983:7). This conception is fundamental to the rest of neo-Darwinian theory since it specifies the manner in which phenomena are to be conceived: we are studying the differential frequency of genetic variants transmitted within and among populations distributed in time and space. In a sense the zero-force law is a kind of fundamental consequence law, describing the basic building blocks of the system and their consequences for a system when it is left to itself.

Neo-Darwinian theory includes a number of forces. It offers explicit descriptions of the processes that constitute the operation of each force. Two kinds of forces may be distinguished on the basis of whether they act, on the one hand, to generate variation, introducing new variants into a population, or, on the other, to sort variation that already exists, perpetuating some variants and not others (Vrba and Eldridge 1984, Vrba and Gould 1986). Among the forces that are responsible for the introduction of variation among individuals in a population is mutation, that is alterations in alleles present in it whose direction is random with respect to the adaptive requirements of individuals. New variants may also be introduced from outside the population via migration and subsequent gene flow. Forces that sort variation may in turn be divided into two groups: those whose operation is deterministic as opposed to random. The distinction turns on whether or not the trajectory of change in the frequency of variants over time is in principle logically implied by a set of initial conditions and parameter values (Sober 1984:110). The precise results of deterministic sorting are predictable in theory. Those of random sorting are not, although theory does afford statistical expectations. The primary force resulting in the deterministic sorting of variants is natural selection, the process whereby different variants tend to leave different numbers of offspring that resemble them in later generations. However, variants may also be sorted randomly, as a result of sampling error in the transmission of genes in finite populations, causing the frequencies of some variants to drift toward unity and others toward zero. Other forces affecting the distribution of variants in populations include inbreeding, non-random (assortative) mating and bias in the gene replication process (meiotic drive). Note that this conception of neo-Darwinism as a theory of forces is not a uniquely philosophical one. It is shared by practicing biologists, as the table of contents and organization of any population genetics text will attest (e.g. Wilson and Bossert 1971, Crow 1986).

The consequence laws of neo-Darwinian evolutionary theory are comprised of descriptions of how these various forces operate that in turn allow deductions concerning their effects on gene frequencies. Consequence laws may be written in English or in mathematical formalism. Today they are largely comprised of the equations of population genetics. Consequence laws for natural selection offer a good example. Models of selection, like other evolutionary consequence laws, contain representations of the mechanistic processes that constitute the operation of the force. Formal selection models build on the implications of the zero-force law for parent-offspring resemblance. To this they add a precise characterization of fitness: the tendency for different variant parents to leave different numbers of offspring as a consequence of differing survival and reproductive probabilities. Once the Darwinian fitnesses of different phenotypes and which genotypes produce them have been specified, these two components can be used to deduce the trajectory of change in the frequency of genetic variants within a population. Population genetics also contains consequence laws for other forces, including migration, mutation, and drift, which specify their effects on the frequency of variants in a population over time. Robert Lewontin's characterization of population genetics as the automobile mechanics of evolutionary theory is apt here: "the job of theoretical population genetics is to set up a mathematical machine into which the various parameters can be dumped, to turn the crank and to produce the kinetics of evolution" (1982:113). Casting evolutionary consequence laws in mathematical terms has two advantages. Deductions of system consequences are more likely to be correct. It becomes possible to compute hypothetical system trajectories expected with the operation of different forces. Comparison of the results against empirically documented patterns can help in the identification of the forces that produced them.

Darwin's original formulation of natural selection as the principal cause of evolution conforms to this structure. It has a zero-force law, an explicit description of the operation of a force, and a simple deduction of the consequence of the force's operation for system change. The first was embodied in the observation that offspring tend to resemble their parents, that is that variation is heritable. Galton and Pearson offered both the statistical tools and data to document this observation, although the processes responsible for it were unknown (Provine 1971). Darwin's formulation of his favored force, selection, built on this simple zero-force statement, adding to it the notions that interactions between the environment and characters for which there was heritable variation caused variants to have different numbers of offspring (Lewontin 1974b). The consequence deduced was that the fittest variants would increase in frequency. The incorporation of Mendelian genetics into Darwinism in the Synthesis offered a far more accurate and richer portrayal of the mechanisms involved and a mathematically sophisticated account of their operation and consequences. It thereby immeasurably strengthened the research program, but did not alter the basic structure of the theory.

Consequence laws of population genetics say nothing about the kinds of physical circumstances that cause their parameters -- for example, the selection coefficients or migration rates -- to take on certain values. That is the job of source laws. They detail the properties of organisms and environments under which we can expect migration, mutation, selection, drift and so forth to come into play. The development of source laws, especially source laws for natural selection, is a major component of evolutionary theory, comprising much of behavioral and evolutionary ecology (e.g. Krebs and Davies 1981). As Sober notes, here lies an important difference between evolutionary theory and physics (1984:50). The source laws that describe the physical conditions for the existence of gravity can be stated with complete generality. In contrast, very large number of physical circumstances can lead to fitness differences among organisms. Hence there are many different source laws for selection. However, the resulting diversity is not wholly chaotic. Two formal or mathematical approaches to the construction of source laws can be distinguished on the basis of whether or not the Darwinian fitness of a given variant depends upon the frequency of other variants in the population. Optimization theory offers source laws for constant fitness. Game theory applies when fitnesses are frequency-dependent, that is when the fitness of one phenotype depends upon the proportion of individuals characterized by another. (Maynard Smith 1978, 1982). I briefly consider the interplay between these two approaches and consequence laws below.

Source laws are written in terms of phenotypes, while consequence laws are written in terms of genes and genotypes. The link between the two is offered by developmental genetics. This component of the evolutionary process, the translation of genotypes into phenotypes, is in practice handled as part of consequence laws. The fitness of a genotype represents the reproductive chances of the phenotype(s) that it produces in a specified environment. Hidden behind the assignment of genotypic fitnesses in population genetic models are hypotheses about the developmental sequence leading from genotype to phenotype. Such hypotheses must accommodate the possibility of developmental complications affecting genotypic fitnesses. Developmental pathways may be influenced by external and internal contingencies. The same genotype may produce different phenotypes in different environments, a phenomenon described by the genotype's norm of reaction (Lewontin 1976). Developmental constraints, pleiotropy, allometry, linkage and so forth, can affect the fitness values associated with different phenotypes (Gould and Lewontin 1979). In practice, we often lack detailed knowledge of these kinds of processes. In its absence, the knowledge that genotypes and phenotypes are correlated in a certain way may be enough to describe evolutionary trajectories (Sober 1984:37).

It is important to be clear on the logical relationships that obtain among the description of an evolutionary force and its source and consequence laws. These have important implications, described below, for how models of empirical phenomena should be built and how theory construction should proceed. Both source laws and consequence laws, including the zero-force state, are necessary for the development of evolutionary theory and its successful deployment in the explanation of particular phenomena. This point is worth pursuing briefly because a casual appraisal of current practice in evolutionary biology would seem to suggest otherwise. Many empirical studies appear to trade either in source or consequence laws but not both. Thus it is worth examining the underlying interdependence of source and consequence laws. I do this below in the context of models of natural selection.

Consider first the optimality approach to the development of source laws for selection. Optimality models yield expectations concerning fitness differences among alternative phenotypes given some set of environmental circumstances and thus allow specification of which phenotype is the fittest. The analysis begins with the identification of a currency, units in which costs and benefits may be measured. Sometimes the currency is a direct measure of fitness, such as lifetime reproductive output. More often it is an indirect measure such as rate of energy intake that, given the organism's constitution and environment, can be argued to cause differences in Darwinian fitness. A second necessary component is the definition of a set of alternative behavioral or morphological strategies available to the organisms, along with a set of constraints, aspects of the environment and the organism's phenotype that, for one reason or another, are assumed constant. The final ingredient is a function that assigns costs and benefits to each of the possible strategies. This can be done empirically or theoretically. Given this information, one computes the strategy that maximizes the measure of fitness, subject to the constraints (Maynard Smith 1978:32-34).

Once a model has been developed, it can be tested by seeing whether the hypothesized optimal phenotype is in fact observed in the population under study.

Usually the goal is to infer the nature of the selective force responsible for the trait in question. However, whether the deliverances of the model could actually have been attained by the population under selection, depends crucially on the messy details -- the auto mechanics -- of consequence laws. For a simple single-locus, two-allele system, where the optimal phenotype is a homozygote, the optimal phenotype will be fixed. In other words, the messy details covered by consequence laws will not confound the predictions of the optimality argument. However, things are not always so simple. For example, in a recent discussion of the dynamics of the hemoglobin locus and sickle-cell trait, Alan Templeton offers an example involving three alleles in which the allele that produces the fittest phenotype (a homozygote) is eliminated from the population under selection (1982:16-22, Kitcher 1985:215). More generally, population geneticists have long recognized that the dynamics of models for more than two alleles at a single locus or for two or more interacting loci bear no simple correspondence to the rank ordering of the genotypic fitnesses (e.g. Crow 1986:97-102,106-108). This has important practical implications for inferences based on optimality models. The hypothesized optimal phenotype may not be observed because of problems with consequence laws, yet the temptation for the modeler is to assume source laws have been incorrectly specified and to fiddle with the constraints or phenotype-fitness function to bring the predicted phenotype into conformity with reality. The result of this kind of curve fitting is the misidentification of the selective forces at work. The problem arises not from essential defects in the optimization approach, but from the fact that optimality models only cover a part of the process whereby organisms come to have the phenotypes they do. The theoretical implication is that both source and consequence laws are required to model the situation completely and make valid inferences about the causes behind it.

The same point applies to the use of game-theoretic arguments to make sense of the selective advantage of characters whose Darwinian fitnesses are frequency-dependent. Here the importance of consequence laws is less well hidden, thanks to the theory of Evolutionarily Stable Strategies (ESS) developed by Maynard Smith. ESS models combine source and consequence laws. ESS theory begins with the game-theoretic portrayal of the costs and benefits of a set of strategies as a function of the strategies played against them. As in optimization theory, costs and benefits are assumed to map directly or indirectly onto fitness values. This portrayal is in turn wedded with a model of genetic transmission for a single-locus haploid system. The result is a set of conditions describing the relationships between fitnesses assigned to strategies that must hold if one strategy, once common in a population, is to resist invasion by an alternative strategy (Maynard Smith 1982, Kitcher 1985:88-97). Thus ESS models combine source and very simple consequence laws. This point is not lost on their originator. A considerable part of Maynard Smith's exposition of the ESS approach is devoted to arguing that the genetic basis of behavioral traits in diploid organisms is well approximated by the simple model used.

This brief description of optimization and ESS approaches to modeling points to one reason for the mutual dependence between source and consequence laws. If source laws about selection are to be put to use to make valid inferences about the forces responsible for some evolutionary phenomenon, they must be coupled with consequence laws. Selective explanations of temporal or spatial variation that lack this component are logically incomplete. They cover only part of the process. This incompleteness diminishes the chance for increases over the long term in empirical adequacy. When empirical evidence fails to meet expectations derived from a hypothesis, a significant portion of the processes operating to produce the recalcitrant result remains hidden from view and thus immune from correction.

The second noteworthy aspect of the relationships among source and consequence laws is more fundamental. It resides in the logical dependence of source laws on descriptions of the processes by which forces operate that are provided by consequence laws. Some understanding of the way a force works is a necessary prerequisite to framing generalizations about the conditions under which it might come into play. Again natural selection offers a good example. Which properties of organisms and environments render certain strategies advantageous depends on the process by which advantage accrues. Costs and benefits associated with different strategies might be identified in a variety of areas, but they are only relevant in the context of selection to the extent that they can be identified with, or be argued to cause, fitness differences. The notion of fitness, survival and reproductive probability, is the key to understanding why costs and benefits matter at all and which costs and benefits matter most. Without a characterization of the selection process provided by its consequence laws, the notions of cost and benefit remain vague, ambiguous abstractions. More generally, the identification of conditions that bring into existence any force depends upon prior explicit notions about processes that constitute the operation of a force. Consequence laws guide the development of source laws.

In this section, I have offered an outline of the structure of neo-Darwinian evolutionary theory in terms of source and consequence laws and tried to clarify the relationships between them. I have argued for the primacy in theory building of explicit description of how a force operates, given formal expression in consequence laws. I have also pointed to the logical necessity for both source and consequence laws in modeling empirical phenomena. I now turn to the implications of this argument for an evolutionary archaeology.

2.2 Source Laws for Archaeology

The successful application of evolutionary theory in archaeology will require explicit source and consequence laws describing the forces responsible for human behavioral variation. Useful contributions to such a research program emerge from a variety of disciplinary sources. Two are relevant here: archaeology and neo-Darwinian evolutionary theory. Taken singly neither offers a complete research program, however they do provide components for one. In addition a group of evolutionary biologists has recently begun to produce a body of theoretical work that promises to be of special relevance for the attempt to develop an evolutionary archaeology. Dual-inheritance or coevolutionary theory, as this approach can be called (Boyd and Richerson 1985:2), recognizes the central importance of neo-Darwinism to any attempt to understand human behavior. In addition it takes seriously the need for explicit consideration of the effects of learning, especially social learning on evolutionary dynamics. In this and the following section I review briefly contributions from these sources and the manner in which they might be integrated into a progressive, evolutionary research program for archaeology. I try to show how each contribution fits into the structure of evolutionary theory outlined in the previous section.

Consider first contributions from archaeology. Archaeologists have taken up the task of building source laws that may prove useful in making inferences about the archaeological record, although they do not recognize their efforts in this direction for what they are. In the preceding chapter, I argued the importance of disentangling two theoretically distinct approaches to "middle-range" theory. One of them, the functional-morphological approach, bases its behavioral inferences on models containing three components. The first predicts the physical consequences of variation in artifact morphology and behavior. Second, physical consequences of particular form-behavior combinations are in turn ranked in terms of suitability in a larger environmental context. Finally the behavior that ranks highest, when paired with the archaeologically documented form, is inferred to have occurred in the past. The ranking of physical consequences, a part of any application of the functional morphological approach, is the result of an accounting of the costs and benefits associated with alternative behaviors and artifact forms. As we have seen above, this same kind of accounting is a key ingredient in optimality models and other source laws for selection. The parallel suggests that the functional morphological approach to "middle-range" theory can be construed as a program to develop source laws for forces like selection that cause deterministic sorting of variants.

Recall too the critique of functional morphology as an incomplete approach to inference. Two problems were identified. The first was the lack of any explicit treatment of the mechanisms underwriting the ranking of consequences. The second was the failure to provide any account of the processes that lead to the association of a particular behavior and artifact form as a result of that ranking. Both deficiencies are a predictable outcome of middle-range theory's lack of concern with the causal processes that operate on human behavior. The first problem is a reflection of the general theoretical dependence of source laws on force descriptions found in consequence laws. As I argued in the last section, costs and benefits are only identifiable when the mechanism by which advantage is gained has been specified. A calculus of costs and benefits has no justification without reference to the processes by which the mechanism operates. Middle-range theory lacks the consequence laws that might provide such a justification. Its proponents even deny their necessity.

The second problem with functional morphology is symptomatic of the requirement, also discussed in the previous section, that logically complete models of evolutionary phenomena contain both source and consequence components. Consequence laws for selection supply the links between the initial conditions that cause fitness differences and the evolutionary trajectory of a system. Inferences based in middle-range theory will only prove useful to the extent that physical consequences and their associated cost-benefit differences prove to be part of the initial conditions that bring into existence forces causing particular form-behavior variants to increase predictably in frequency in the population under study. Consequence laws allow explicit treatment of the processes that cause the associations between artifact form and behavior postulated by functional morphological models. They therefore provide the second missing ingredient in behavioral inferences from the functional-morphological approach.

From an evolutionary perspective, "middle range" theory emerges as a premature program to develop source laws for deterministic forces that sort behavior-form combinations. It is premature because it is being carried out without a concurrent attempt to describe forces and how they operate and to deduce the implications of their operation for system trajectories. This is the major lacuna in contemporary theoretical work in archaeology. The same perspective suggests that "general theory" be regarded as a program to develop force descriptions and their implications for dynamics in consequence laws. Thus the argument of the previous chapter, that archaeology requires general theory as a foundation for sound inferences about the past, can be restated in evolutionary terms. *Theoretical progress in archaeology depends on the development of explicit force descriptions and consequence laws for human behavior.*

2.3 Evolutionary Forces Relevant to Archaeology

What might the forces of an evolutionary theory of human behavior look like? Until recently the only serious attempt to offer an allegedly complete answer to this question was to be found in human sociobiology. Sociobiological theory is a direct and successful extension of neo-Darwinism to the evolution of social behavior (reviews in Wilson 1975, Krebs and Davies 1981, Trivers 1985). There are at least three competing accounts of the precise relevance of sociobiological theory to human behavior (Kitcher 1985:15). The first is the program inaugurated by E.O. Wilson (1975) that is widely regarded as the source of the entire approach. Wilson's revision and elaboration of this program in answer to his critics constitute the second program (Lumsden and Wilson 1981). The third was launched by Richard Alexander (1974, 1979). It is by far the most influential among anthropologists.

The principal difference between the early Wilson program and the Alexandrian one lies in the emphasis that the former gave to limits on human behavior set by neo-Darwinian processes. Wilson was primarily interested in showing that important aspects of contemporary human social behavior could not be altered by tinkering with social environments (Kitcher 1985:126-132, Dawkins 1982:Ch. 2). On the other hand, primary concern of the Alexandrian school is with analysis of behavioral variation in terms of its fitness consequences. While Wilson's efforts were aimed at deriving conclusions about the impossibility of modifying human behavior, Alexander stressed behavioral flexibility. Despite the differences in emphasis, the application of sociobiological theory to the analysis of human behavior in both cases rests on the claim that the forces, and thus source and consequence laws, governing human behavior are identical to those comprising neo-Darwinian theory. In other words the dynamics of human behavior are wholly explicable in terms of the differential transmission of genetic variants in populations, driven nearly exclusively by natural selection. The Lumsden and Wilson program represents something of a retreat from this claim (see below).

Over the past decade, the Alexandrian program alone has inspired a significant body of new empirical research and reinterpretation of older anthropological work on human behavioral variation (e.g. Chagnon and Irons 1979, Betzig et al. 1988). As a result, it is here that we find the clearest version of the argument for the sufficiency of unalloyed neo-Darwinian theory for the explanation of human behavior. The Alexandrian program stresses the universality of genetically controlled human behavioral dispositions (e.g. Alexander 1974, 1979, Irons 1979, Alexander and Flinn 1982). Human behavioral variation is entirely due to facultative responses to environmental variation. Individuals who find themselves in different environments are genetically endowed with the ability to develop behaviors that maximize their inclusive fitness in those environments. The primary justification for this account can be termed "the argument from natural origins" (Boyd and Richerson 1985:13). It is that human beings and human behavioral capacities, loosely referred to in this context as "learning" and "culture", evolved by the same Darwinian processes responsible for the evolution of other species. These capacities must have been favored by natural selection. Hence they must cause humans to behave in adaptive, fitness-maximizing ways (e.g. Flinn and Alexander 1982:386, Durham 1981:219). The source and consequence laws of neo-Darwinian theory are harnessed to account for the fixation, deep in evolutionary history, of abilities to make fitness-maximizing behavioral adjustments.

There is, however, an obvious incongruity between the theoretical justification of the Alexandrian program and its empirical application. The mismatch suggests why the forces of neo-Darwinism may not alone provide a dynamically sufficient account of human behavioral variation. Empirical work inspired by the Alexandrian approach is largely devoted to arguments that this or that behavior enhances inclusive fitness in certain ethnographic situations. The machinery of neo-Darwinian theory is used to explain the existence of particular behaviors. The most sophisticated applications in terms of method feature optimality models reviewed above (reviewed in Smith 1983,

1987) or other explicit mathematical treatments (e.g. Kurland 1979) of variation in Darwinian fitness or its correlates among alternative behaviors. Thus empirical practice matches what would be appropriate if behavioral variation were caused by genetic variation, that is if different behaviors were genetically heritable, and if natural selection were directly sorting heritable behavioral variants. Yet the foundation for the program denies that this is the case. It insists that selection has created decision-making abilities that in turn are directly responsible for behavioral variation. The Alexandrian program is characterized by the absence of any treatment of the causal mechanisms by which particular behaviors came to be present in the populations studied (Barkow 1984, Kitcher 1985:282-284). Attempts to model such mechanisms are seen in the Alexandrian program as irrelevant and dismissed as "mathematical and speculative sociobiology", to be contrasted with "empirical human sociobiology" (Borgerhoff Mulder 1987:29, Caro and Borgerhoff Mulder 1987). In considering the relevance of neo-Darwinian models to human behavior, the crucial question is to what extent do the abilities of organisms to modify their behavior in response to environmental variation introduce novel evolutionary forces that are not covered in traditional neo-Darwinian models.

To answer this question it is useful to distinguish two broad categories of phenotypic flexibility: individual and social learning. Social learning refers to the process whereby individuals modify their behavior by observing others, while individual learning refers to the processes whereby individuals alter their behavior based on their own abilities to digest environmental input. If forces generated by individual and social learning have significant effects on human behavioral variation, a satisfactory evolutionary theory of human behavior will have to include them by developing the relevant source and consequence laws. In the next two sections I review the effects of individual and social learning on behavioral variation. It will emerge that if causally adequate accounts of behavioral variation are the goal, then individual learning and especially social learning require explicit treatment. Symptomatic of this state of affairs is the fact that both individual and social learning may lead to systematic departures from predictions grounded in strict neo-Darwinian orthodoxy. Thus accounts of individual and social learning are essential to a complete theory of human behavior. On the other hand, since neo-Darwinian forces are responsible in the last analysis for their existence, both forms of learning must ultimately be understood in a neo-Darwinian evolutionary framework.

2.3.1 Individual Learning

Individual learning is phenotypic flexibility generated by individual organisms as direct response to environmental variation. Individual-learning abilities vary across a wide continuum of complexity in the cognitive machinery required to carry them out (Bonner 1980:34). At one end of the continuum lie simple forms of phenotypic flexibility that rely on programmed responses to phyletically typical environmental variation where the connection between environmental stimulus and organismic response is invariant over the lifetime of the organism (Mainardi 1980:227). At the other end are more complex forms of associative learning made possible by learning organisms' ability to associate initially meaningless phenomena with those that are already recognized to be of importance (Bateson 1983:486). More complex forms of learning make it possible for an organism to alter the behavioral rules that underlie the simpler forms of phenotypic plasticity.

Learning is based on acquisition by an individual organism of new information about the environment, its storage, and later integration into behavior of the organism (Plotkin and Olding Smee 1982:443). What makes this possible? Learning requires that the organism bring to experience a great deal of prior information in the form of cognitive mechanisms or rules for learning. The rules provide a learning organism with criteria that enable it attend salient characteristics of the environment, to evaluate different outcomes of interactions with the environment, relate them to initially neutral or meaningless events, and to choose appropriate courses of action as a result (Bateson 1983, Pulliam and Dunford 1980:12-19, Cosmides and Tooby 1987:286).

Consider the kinds of background information required by an organism engaged in individual associational learning. First there must be a set of assumptions about the environment that specifies the conditions under which two events, a neutral event and its outcome, are likely to be associated. These assumptions include temporal conditions. An individual must "know" that an outcome that occurs within a certain time after a neutral event or behavior is likely to be associated with it. Consider an organism that becomes ill some time after eating novel food. If the interval between ingestion and illness is on the order of days, the organism is unlikely to associate the two. In addition the organism must assume that certain kinds of outcomes are likely to be associated with certain kinds of neutral events. For example, gastric distress is likely to be related to the ingestion of novel foods and not familiar ones, but external stress is not. In other words, rules of the first sort enable organisms to "register" a connection between causes and their effects. Second, there must be a rule specifying whether the effect, and hence the neutral event associated with it via operation of rules of the first sort, is evaluated positively or negatively. Gastric distress is bad. Third, the organism must possess clues concerning the manner in which evaluations in certain contexts should map back onto behavior. Given that the novel food is associated with bad sensations, what should be done about it? Finally, the organism must be equipped with an initial behavioral disposition that makes the neutral event neutral and yet permits the individual to be exposed to it. The organism must be predisposed to try novel foods (Boyd and Richerson 1985:84-87).

The rules not only constrain the course of individual learning, they make it possible in first place. Because learning ability depends on the prior existence of rules, any explanation of phenomena in terms of learning must include an hypothesis about the content of the rules that make learning possible. In turn the rules themselves must be understood as a product of evolutionary processes. In fact, the taste aversion experiments from which the above examples are drawn are among the first persuasive pieces of evidence in favor of the notion that rules for learning can only be understood as the product of adaptation by natural selection to specific ecological conditions (Domjan 1980, Johnston 1981). To the extent that those conditions are divergent among species, the rules will be variable as well, while universal aspects of learning are the result of ecological factors common to all learners. Thus the argument from natural origins is essential to understanding the origins of rules for individual learning. In an environment that is likely to vary in time and space, a individual able to develop the locally adaptive behavior is clearly at a selective advantage, as long as the costs incurred in learning that behavior do not outweigh the benefits. We can expect natural selection to have endowed organisms with abilities to alter their phenotypes in response to environmental perturbations. Thus phenotypic flexibility and the rules for individual learning that underlie it are deductive predictions of neo-Darwinian theory.

However, acceptance of the relevance of the argument from natural origins to understanding individual learning does not imply that models of genetic transmission are sufficient for understanding behavioral variation caused by individual learning (Plotkin and Olding Smee 1982, Cosmides and Tooby 1987). The rules for learning will enhance fitness via the results of their operation, averaged over the behaviors they generate in the ecological situations a lineage is likely to encounter. The link between learned behavioral variation and fitness is mediated by learning rules. Thus if an exhaustive delineation of the causal process behind a particular kind of behavior is required, it must be in terms of the operation of the rules, not in terms of the effects of the behavior on fitness (Kitcher 1985:329, cf. Smith 1987:228-229).

Two aspects of the outcome of operating with learning rules point to this requirement. The first is that learning organisms make "mistakes". Precisely because they are general guides to learning, the rules cannot be expected to lead to the development of behaviors that enhance Darwinian fitness in all cases. When they do not, the resulting behavior pattern can be considered a mistake, from the point of view of natural selection. Mistakes may intrude because the rules may permit associations between effects and neutral events when the two are in fact unrelated, or because the scale for evaluating effects may be unreliable in the current environment.

Recent work on inbreeding avoidance in humans offers an illustration. The sociobiological version of the Westermarck hypothesis suggests that the human propensity to avoid sibling incest is underlain by a learning rule that causes individuals of the opposite sex reared together in early childhood to develop sexual disinterest in one another in later years (van den Berghe 1983, Bateson 1983). When siblings are reared in the same household, the result is adaptive. However, when non-siblings are reared together, the same kind of sexual disinterest develops, a result that does nothing to enhance fitness and may even reduce it by reducing the size of the pool of potential mates available to unrelated co-reared individuals. The point here is not the accuracy of the Westermarck hypothesis, but that behavioral variation cannot be predicted accurately without taking into account the operation of the rules that are directly responsible for it. In a given set of environmental circumstances, the rules for learning will not necessarily favor the same behavioral variants as natural selection. In other words, source laws for individual learning, specifying what kinds of behavioral variation will be favored by learning rules in certain kinds of environments, will not necessarily be identical with the neo-Darwinian source laws for selection. Learning rules create a force that may systematically favor behavioral variation of neutral or negative selective value.

The second aspect resides in the fact that operation of learning rules creates the possibility for novel temporal dynamics that cannot be captured in strictly neo-Darwinian models. Individual learning makes possible systematic change in behavior patterns in response to altered environments on a time scale orders of magnitude shorter than that possible when the only mechanism at work is natural selection sorting genetic variants. The fact that they make possible such rapid, facultative responses to altered circumstances is among the primary reasons for the fixation of the rules in the first place. In addition, individual learning can be expected to have feedback effects on the dynamics of neo-Darwinian process. It will alter the dynamics of genetic evolution through the Baldwin effect, in which learned behavioral accommodations set up new selection pressures that in turn direct long-term phylogenetic change (Bateson 1982). There is also the possibility that individual learning speeds up genetic evolution through facilitation of the process by which behaviors become genetically encoded (Maynard Smith 1987).

Similar arguments can be made for behavior that is the result of more sophisticated forms of individual learning involving what we think of as "rational calculation". The processes behind rational calculation are fundamentally analogous to individual associative learning. The difference resides in the fact that learning trails are not confined to organism-environment interactions, but are internally generated. In other words, individuals must possess sophisticated cognitive abilities that allow them to rehearse encounters with the environment in their heads (Campbell 1974:41, Boyd and Richerson 1985:92-94). However, the process is still built on the same kinds of learning rules discussed above. Here again there is room for error, that is departures from fitness maximizing outcomes, and the possibility of change in behavior patterns on very short time scales.

As a result of the above factors, knowledge of learning rules allows accurate prediction of behavior, while understanding manifest behavior directly in terms of fitness allows only approximate prediction (Tooby and Devore 1987:198). However, any attempt to suggest the need for explicit treatment of learning rules in accounts of behavioral variation that is proximately caused by learning runs into an obvious and powerful objection: the predictions available from analysis of manifest behavior are often remarkably good. Witness the phenomenal success of behavioral ecology and sociobiology in accounting for behavioral variation among species for which phenotypic flexibility based on individual learning is clearly important. Over the past two decades, field studies have revealed how individual members of a variety of bird and mammal species are able to alter their behavior in response to variation in environmental parameters like food abundance and patchiness, resulting in striking contrasts in social organization among members of the same species living in adjacent areas (e.g. Wrangham and Rubenstein 1986). Nor is this success limited to non-hominids. In the human case, particularly noteworthy are insights into foraging behavior of contemporary hunter-gatherers based on optimality models (Smith 1987, Hill et al. 1987).

Paradoxically, understanding learning mechanisms is crucial to understanding the success of a research program that has largely ignored them. An explicit account of the role of learning rules makes it possible to anticipate conditions under which straight neo-Darwinian accounts will further our understanding of learned behavior. Predictions based on the fitness effects of behavioral alternatives that ignore the mediation of learning rules often prove to be quite good approximations of what is observed for two reasons. First, as we have seen, it was on the basis of the fitness effects of the behaviors generated by the rules that the rules were fixed in the first place. Second, and of more immediate importance, the range of environments in which the rules were fixed does not differ in significant ways from those faced by the individuals whose behavior is being predicted. Environmental continuity insures that the rules still have fitness-enhancing behavioral effects similar to those responsible for their fixation. If these two conditions hold, then predictions based on fitness-maximizing criteria should fare quite well. They will do so because, to a large extent, the causal nexus linking environment, manifest behavior, learning rules, and selection is still in place. However, as the range of environments faced by individuals departs from those in which their learning rules were fixed, we can expect increasingly systematic departures from predictions that do not take the rules into account. Environments faced by humans living in complex societies over the past several thousand years are vastly different from those in which our ancestors spent their evolutionary history during the Pleistocene. As the incest avoidance example discussed above suggests, these are precisely the conditions in that attention to proximate mechanisms becomes important both for accurate prediction and causal analysis.

Faced with human behavior from such contexts, the Alexandrian program delivers post-hoc accommodative interpretations of human behavior based on metaphorical renderings of neo-Darwinian theory (e.g. Dickemann 1979). The absence of attention to mechanisms precludes the possibility of building rigorous models. It also prevents use of a powerful strategy for evolutionary inference, the use of imperfection as evidence that a feature is the product of a mechanism as opposed to an omniscient designer (Gould 1986). The fact that learning mechanisms fail to deliver adaptive results in novel circumstances offers some of the best evidence that they are the product of a contingent history of natural selection in past environments.

The need for explicit treatment of the behavioral rules that underlie simple phenotypic plasticity has been given formal recognition in the optimality literature. Workers have attempted to relate optimal strategies derived from theory to the actual rules of thumb that organisms use to achieve them and in turn to offer optimality analyses of variable rules of thumb (Krebs et al. 1983). Such models are extensions to traditional optimality models that take into account proximate mechanisms, delineating, for example, just how an animal might go about learning to forage optimally. From the perspective on the structure of evolutionary theory developed above, this work may be regarded as an attempt to develop consequence laws for learning. Theoretical progress in the evolutionary treatment of behavioral variation caused by individual learning will have to build on this foundation.

Progress toward the development of a causally and dynamically sufficient evolutionary theory for behavioral variation in learning species requires explicit recognition of the forces introduced by individual learning. This in turn necessitates the development of consequence laws that describe the contents of the rules and allow us to model the dynamics of individual learning and source laws specifying conditions under which learning rules operate and the behavioral variants that are favored by them. It is clear that rules for learning are shaped by neo-Darwinian processes. Hence a successful research program designed to document human learning rules must have a neo-Darwinian foundation.

2.3.2 Social Learning

The ability of individuals to engage in social learning presents more severe complications. To see why requires a precise definition of social learning. In the recent literature, the term has been loosely associated with a wide range of phenomena, some of which are better viewed as forms of individual learning discussed above, for example habitat imprinting (e.g. Galef 1976:82, Cavalli-Sforza and Feldman 1981:7). The salient difference between individual learning and social learning lies in the origin of novel behavioral variants. In individual learning they are endogenously generated. In social learning they are derived from conspecifics. In terms of the argument developed here, social learning is understood as the transfer by imitation or teaching of information from one individual to another that results in their sharing behavior patterns in similar environments. (Plotkin and Olding-Smee 1981:230, Mainardi 1980:229, c.f. Boyd and Richerson 1985:35). Even with this strict definition, social learning varies in the complexity of the information transferred and the sophistication of the cognitive apparatus required to handle it.

At the simple end of the continuum lies what has been called guided learning or local enhancement, in which subordinate or young organisms follow dominant or older individuals, thereby exposing themselves to the same external stimuli that engender similar responses because of common rules for learning (Galef 1976:83-84, Mainardi 1980:229). Here the information acquired from conspecifics concerns the performance of simple bodily movements. A likely example is the habit of opening milk bottles that spread from a single place of origin during the 1930's and 40's throughout populations of titmice, scattered across England (Hinde and Fisher 1951, Galef 1976:86). The behavior is apparently based on the disposition of individuals to peck at objects at which they observe conspecifics pecking. Naive individuals acquired from models the tendency to peck in a certain way at a novel item. Subsequent random variations in performance and the evaluation of their effects via rules for individual learning resulted in the emergence of the full behavior. Although individual learning had a role in polishing an individual's performance, the process was initiated by the transmission of a very simple behavioral instruction.

Forms of social learning that lie further along the continuum have been characterized as "true imitation". They involve sudden acquisition from another individual of complex behavioral instructions and their immediate implementation in new behavior patterns (Mainardi 1980:229). The textbook non-human example is the spread during the 1950's and 60's through an island colony of Japanese macaques of novel food processing techniques. These were the habits of washing sweet potatoes in the sea to rid them of sand and of separating wheat from sand by flotation, that is throwing wheat mixed with sand onto the water and skimming the clean grains from the surface. The techniques spread fully perfected from their young inventor to her age mates who as adults would pass them on to their offspring (Nishida 1987, Kawai 1965).

The most complex forms of social learning are, of course, to be found among modern humans. This complexity is derived in part from the fact that social learning among humans is often mediated by symbols, in particular by language. Some anthropologists, the traditional custodians of this domain, and more recently a few archaeologists have insisted that what humans learn socially is a system of arbitrarily meaningful symbolic constructs called culture and that all human behavior is symbolically mediated (e.g. Schneider 1976, Sahlins 1976, Hodder 1986). For my purposes, this construction of human social learning is unhelpful. It is not at all clear how much of human behavior now or in the past is learned through symbols as opposed to direct copying of behavioral phenotypes. The importance of symbols is doubtless highly variable in time and space since the advent of modern humans and has surely increased greatly during hominid evolution. These are points to which archaeologists should be especially sensitive, given the temporal span of the archaeological record. Symbolically mediated social learning shares the evolutionary properties of ordinary social learning. In fact, from an evolutionary perspective, symbols may prove to be merely a means of socially transmitting complex behavioral information quickly and cheaply. Henceforth I shall use the terms social learning and cultural transmission synonymously.

Like individual learning, cultural transmission is a capacity that depends upon rules that both make it possible and place constraints on the kind of behavioral variation that results. It is useful to distinguish two sorts of rules that govern its operation. Rules of the first sort specify what can be called the structure of the cultural transmission system. Rules of the second sort create forces that act upon the transmission system, given its structure (Boyd and Richerson 1985:2-3). Structural rules in effect identify who learns from whom using characteristics of organisms that are not themselves culturally transmitted. Structural rules thus specify for example whether the transmission system is vertical, oblique or horizontal, that is whether learners should learn from parents, other members of their parents' generation or their peers (Cavalli-Sforza and Feldman 1981:54). Other parameters set by structural rules include the number of models each learner encounters before learning and the influence that each model has on what is eventually learned. Note that non-parental transmission is common not only among humans: potato washing among macaques was transmitted horizontally at first and then vertically. Horizontal transmission almost certainly figured in the spread of milk bottle pecking among titmice.

Rules of the second sort create forces by biasing the transmission process. When bias rules operate, information transmitted to learners is not a random sample of the information that exists in the population of models encountered by learners. Bias rules make it more likely that some forms will be transmitted than others. They may do this in a number of ways. The most obvious means is through direct bias. Direct biases enable a learner to decide whether or not to incorporate a given cultural variant, among two or more to which it has been exposed, into its repertoire, based upon an evaluation of the variant itself. The exercise of direct bias requires that a learner judge the trait itself, either through trial and error or rational calculation. The learner must connect effects of a variant to the variant and evaluate those effects on some scale, either by direct experiment with the variant or by observation of models' experience with it. This requires application of a set of learning rules like those responsible for individual learning to pre-existing cultural variants (Boyd and Richerson 1985:135). Direct bias has been noted as an important force affecting cultural transmission under a variety of terminological guises: cultural selection (Cavalli-Sforza and Feldman 1981:15-16), genetic mediation (Durham 1982:302), and epigenetic rules (Lumsden and Wilson 1981:7). Likely examples are to be found in human food preferences. Lactose malabsorption is a genetically transmitted trait that causes its bearers to become ill after consuming fresh milk. The frequency of the gene is high in Mediterranean populations and low in northern European ones, and is probably responsible for differences in the socially learned pattern of raw milk consumption in the two areas (Durham 1982:306).

Other forms of bias may arise in cases where it is difficult or costly in terms of time and energy for individuals to evaluate variants directly. Indirect bias offers an example. Indirect bias rules specify the characteristics (indicator traits) of models from whom individuals should preferentially learn or not learn other traits. If there is a correlation across models between the indicator trait and any second trait, the value of the latter associated with the characteristic favored by indirect bias will increase in frequency in the population as a whole (Boyd and Richerson 1985:252-254). Indirect-bias rules will likely be fixed when some readily observable characteristic of individuals is a reliable correlate of fitness in a wide variety of environmental contexts.

The rules for social learning are themselves the product of natural selection. The function of the rules, the effect that caused their fixation by selection, is to increase the likelihood that an individual will acquire selectively advantageous behavior in its local environment from conspecifics. The rules and the capacity for culture that they make possible are designed by selection to increase the chances that the contents of the cultural transmission system are fitness enhancing in neo-Darwinian terms. There are two broad categories of benefits (see below). First, behavioral variants based on individual learning are confined, at least in the near term, to the single individual with whom they originated. Cultural transmission makes possible the transfer of variants acquired via individual learning to others. Individuals do not have to rely on themselves to generate new, potentially fitness-enhancing behaviors. They are thereby able to avoid individual learning trials that may be dangerous or costly, consuming time and energy that might be invested in other activities that increase fitness and yet still reap some of the benefits in a variable environment afforded by phenotypic flexibility. Second, individuals may be able to acquire through social learning complex behaviors for which genetic variation simply does not exist. In other words, social learning may make it possible to transmit adaptive information that cannot be transmitted genetically. Thus it turns out that social learning must be understood in terms of the argument from natural origins. However, as proved to be the case with individual learning, this does not imply that explicit consideration of social learning rules is unnecessary for the explanation of cultural variation.

The reasons social learning requires explicit extensions to neo-Darwinian theory are related to those discussed above in connection with individual learning. The common elements can be treated briefly here. A causally adequate understanding of the processes behind behavioral variation driven by social learning requires understanding the rules for learning. The reasons for this requirement are familiar. First, despite the fact that those rules are designed by selection to enable individuals to learn fitness enhancing behaviors, there are reasons to suspect that some of the behaviors transmitted under them will not have this effect. Because of such errors, there will be departures from predictions based on neo-Darwinian fitness. Second, operation of the rules for social learning clearly has novel dynamic consequences for the distribution in time and space of behavioral variants. It is here that the contrasts with neo-Darwinian expectations are even more striking than was the case with individual learning. Unlike individually learned variants, novel cultural variants do not perish along with the individuals with whom they originated. Rather they may spread directly among individuals, often within a single generation. As a result, social learning introduces a second inheritance system whose content informs behavioral phenotypes, in addition to the genetic inheritance system to which it owes its existence. Because it brings into existence a second inheritance system, social learning, unlike individual learning, has immediate population-level consequences for behavioral variation that do not depend on behavioral feedbacks to the genetic system.

These arguments imply that the commonly encountered sociobiological position that social learning is merely an elaborate form of phenotypic plasticity without implication for evolutionary dynamics that cannot be handled strictly within the framework of neo-Darwinism is simply false (e.g. Flinn and Alexander 1982, Harpending et al. 1987:137). It is important to realize that this is the case even if the assumptions of the Alexandrian program were true: that nearly all human cultural variation is determined by genetically conditioned bias rules and that the net effects of the exercise in bias rules, in concert with structural ones, leave no room for the existence of transmittable cultural variation. Were these two proposition correct, in the final analysis, the ultimate causes of cultural evolution would be natural selection, and more broadly neo-Darwinian processes, acting on genetically transmitted dispositions. Nevertheless, neo-Darwinian models would still need to be extended to handle individual and social learning, if the goal is to understand the actual causal processes behind human behavioral variation.

Because social learning brings into existence a second inheritance system, these additions would include a zero-force law to describe the structural rules of the transmission system and its behavior when no forces intervene. New consequence laws would describe the operation of various forces, in this case the bias rules, affecting cultural transmission and their effects on the dynamics of behavioral variation. Finally, new source laws would be required to indicate the properties of cultural variants, or of their behavioral expression, that in certain environments are favored by the bias rules.

However, the brief for the explanatory inadequacy of unadorned neo-Darwinism in coping with social learning does not end there. Additional complications arise from the existence of transmittable variation in the information pool shared by social learners. Such variation will exist if the rules for individual learning and the bias rules for cultural transmission, are not sufficiently error free or strong to eliminate alternative cultural variants from a population. If there is transmittable or heritable cultural variation, then there is scope for the operation of a second set of emergent forces -- natural selection and drift -- to sort it directly, unmediated by the operation of bias forces.

The operation of selection on cultural variation will favor variants that increase the chances that their bearers will become models. The resemblance between it and its neo-Darwinian analogue will be a function of the extent to which the structure of the cultural transmission system is "symmetric" with the genetic one. Symmetry refers to the degree to which the cultural variants of learners are a product of equal contributions by both biological parents (Boyd and Richardson 1985:11). When the structural rules are asymmetric, that is when the rules allow learners to use cultural models that are not genetic parents, the variants that confer the greatest chances of becoming a cultural model need not be the same as those conferring the greatest chances of becoming a biological parent (Boyd and Richerson 1985:173-4). In other words, the natural selection of cultural information under asymmetric transmission structures, need not favor those variants with the highest inclusive fitness. The extent of the departures from neo-Darwinian optima will depend on the extent to which the structure of the transmission system departs from Mendelian specifications. As a result, the source laws for natural selection of cultural information will contain systematic departures from their neo-Darwinian analogues.

A further possible consequence of the existence of heritable cultural variation is that both structural and bias rules for social learning may be underpinned not by genetic variation but by cultural variation. In this case, the rules governing learning are cultural instructions, with their origin in the natural selection of culturally specified variant rules. The rules will be designed by selection to increase the chances that individuals acquire cultural variants that will increase their chances of becoming models. If the transmission system under which the rules were selected is asymmetric, then they can be expected to favor the acquisition by learners of variants that do not necessarily maximize inclusive fitness. Here again, when asymmetric transmission is important, the source laws describing which cultural variants are favored by direct bias will probably not resemble those for learning rules grounded in genetic variation.

2.4 Toward a Coevolutionary Synthesis

Attempts to explore formally the implications of individual and social learning in an evolutionary framework and to elaborate the neo-Darwinian theory of forces to take them into account can be divided into two schools. The first, whose sole representatives are Lumsden and Wilson (1981), represents Wilson's attempt to answer critics of his initial research program for human sociobiology. Lumsden and Wilson profess to be interested in offering an analysis of the interactions of culture and genes. However, the models that they offer of these interactions largely omit any serious treatment of cultural processes or their effects from the outset. In the cases where these are included initially, they are often dropped from the models in the interest of analytical tractability (Maynard Smith and Warren 1982, Kitcher 1985:331-94). Lumsden and Wilson's modeling efforts fail to take cultural effects seriously from the beginning, hence it is hardly surprising that their results appear to minimize their importance.

The second school can be called the co-evolutionary or dual-inheritance approach (Boyd and Richerson 1985:2). The basic framework for the effort is provided by the argument from natural origins. Thus the dual-inheritance approach is founded on one of the core principles of human sociobiology, its insistence that neo-Darwinism is fundamentally relevant to understanding individual and social learning. The fact that it delivered this principle is testimony to the success of human sociobiology as a research program, despite that fact, argued above, that it mistook the precise nature of its relevance. The argument implies that an integral part of the task of understanding cultural transmission lies in modeling in a neo-Darwinian framework the conditions under which cultural transmission arose. The outcome of such theoretical efforts will provide the answers to a set of related questions. What kinds of environmental conditions favor the evolution of rules for social learning? Does the fact that natural selection of genetically transmitted variants was the means by which social learning evolved place constraints on the content of the rules? Are different background conditions and different kinds of environments likely to cause different kinds of social learning?

These are big questions and definitive answers to them will only come over the long term. A first step is the development of mechanistic models of the processes involved. These will comprise the source laws for the selection of cultural transmission. Actual answers will come later in the form of tests of which models are likely to apply to various species, including humans.

Our earlier discussion of the relationship between source and consequence laws should make it clear that derivation of source laws for the evolution of cultural transmission will require models of the background conditions constituting and forces that operate upon both the genetic and cultural inheritance systems. These are provided by zero-force and consequence laws respectively. In the case of the genetic inheritance system these are derived from neo-Darwinian population genetics. For individual and social learning, they have recently been developed by several authors, most importantly by Cavalli-Sforza and Feldman (1981) and, simplifying and generalizing their models, Boyd and Richerson (1985). The new models portray the dynamics of both individual learning and cultural inheritance and their effects on behavioral phenotypes.

By combining models of genetic inheritance and individual and social learning, it is possible to deduce expectations concerning the different kinds of learning rules that would be favored under different background and environmental conditions. This effort lies at the heart of the dual-inheritance research program. Although such modeling efforts are in a preliminary stage, some insights are already available. As outlined below, these suggest that a variety of structural and bias rules for cultural transmission are probable outcomes of natural selection.

Consider first a population in a constant environment divided among individuals who acquire their phenotypes through social learning of a dichotomous trait and those who acquire it thought genetic transmission. The phenotype favored by selection can be acquired either through genes or through culture via vertical and oblique transmission from members of one generation to the next. Cultural transmission is governed by a parameter that describes its efficiency, the probability that models with the favored phenotype transmit it accurately to individuals of the next generation. The efficiency of genetic transmission is assumed to be unity. Given these conditions, it can be shown that genetic transmission will always replace cultural transmission in the population, as long as the efficiency of cultural transmission is less than one. If the efficiency of cultural transmission equals that of genetic transmission, a polymorphism will result in which social learners will be at roughly the same frequency -- presumably low -- at which they were introduced into the population (Cavalli-Sforza and Feldman 1983:4994). The substantive result from this exercise is that if cultural transmission is to be favored by selection, it must offer selective advantages that cannot be had from genetic transmission. Accurate transmission is not enough. Several more complex models suggest in a general way some of the areas in which those advantages might lie and the character of the structural and bias rules under which they would accrue.

Cavalli-Sforza and Feldman suggest one when they note that cultural transmission might be favored by selection if it "permit(s) adaptation to a great variety of challenges" (1983:4995). They go on to formalize the argument by adding a component to the model described above in which a second trait is introduced that can be culturally transmitted but for which no genetic variation exists. If a variant of this trait is selectively advantageous and vertical-cultural and genetic transmission are equally efficient, then social learning will replace genetic transmission of the trait in the population (1983:4995-4996). Cultural transmission systems characterized by symmetric structures but lacking genetically based bias rules will evolve through natural selection when they make available adaptive behaviors that cannot be generated by genes.

Selective advantages may accrue to social learners in other ways as well. Several modeling efforts suggest that, under certain conditions, social learning will spread in a population of individual learners in a temporally fluctuating environment. Boyd and Richerson have constructed two such models. The first attempts to elucidate the conditions under which selection will favor increases in the importance of vertical and oblique cultural transmission at the expense of individual learning in the determination of an individual's behavioral phenotype in a changing environment. Each population member is characterized by a genetically transmitted parameter that represents the extent to which an individual relies upon individual learning trails or social learning in determination of the value of a continuous phenotypic trait. Whether or not the importance of social learning increases over time depends on several other parameters whose values may vary. One of these is the rate at which the environment fluctuates. This can be characterized in terms of temporal autocorrelation in the value of the optimal phenotype, the chance that the optimal phenotypic value will be similar from one time period to the next. Other parameters in the model are the costs and errors associated with individual learning and the efficiency of cultural transmission. Boyd and Richerson show that the importance of cultural transmission in phenotype determination will increase if environmental autocorrelation is moderate to large, if errors introduced by individual learning and costs associated with their reduction are large, and if cultural transmission is relatively error free (1985:110-115). The second set of models compares the geometric mean fitness of two populations, both equipped with equal individual learning abilities, one with vertical and oblique cultural transmission and one without. Although the results depend in complicated ways on learning and transmission error rates, in general the cultural population is favored when environments are moderately to highly autocorrelated (1985:117-127).

Similar results emerge from a much simpler model formally developed by Rogers (1988) and based on an argument originally due to Boyd and Richerson (1985:16, cf. Harpending et al. 1987:135-136). Here the relative importance of individual and social learning is captured in terms of the frequency of individuals who learn their phenotypes individually versus the frequency of individuals who acquire their phenotypes through cultural transmission. This treatment collapses the importance of social learning for an individual to a dichotomous scale. A further simplification ignores the effects of selection on culturally transmitted variation in the interests of analytical tractability. The rate of environmental fluctuation is represented not by autocorrelation but in terms of the probability that one of two dichotomous behavioral phenotypes, acquired either by individual or social learning is optimal. Despite these simplifications, the results agree with those described above: social learners predominate in the population when individual learning is costly relative to social learning and when environmental perturbations are relatively infrequent.

I have analyzed numerically a version of the Rogers model in which selection can affect simultaneously the frequency of social and individual learners and the frequency of cultural variants that determine behavioral phenotypes of social learners. This model yields two additional insights into the problem. First, there appears to be a threshold effect governing the importance of cultural transmission. Small decreases in cost of cultural transmission relative to individual learning cause large increases in the equilibrium frequency of social learners. The second insight emerges from a comparison of the trajectories of the frequency of social learners in two populations, one in which cultural transmission is vertical and oblique and the other in which cultural transmission is horizontal. If learning costs and rates of environmental fluctuation are the same in both cases, the equilibrium frequency of social learners is always higher under horizontal transmission than under vertical and oblique. This result makes sense since horizontal transmission offers more up-to-date information about the currently adaptive phenotype in a fluctuating environment. It is the efforts of individual social learners that tend to keep the information up-to-date. Horizontal transmission allows social learners to take better advantage of the learning trials of individual learners without paying the costs of individual learning trials. This implies that if horizontal and vertical-oblique transmission are equally costly, social learning populations will tend to have horizontal transmission structures. Hence if social learning is favored, it is likely to be in the context of an asymmetric transmission system.

Formal treatment of the evolution of cultural transmission systems characterized by various bias rules in an acultural population have yet to be developed. However, the foregoing models for individual learning offer some guidance on what might be expected. We can expect that bias rules would have effects similar to those of individual learning in the above models, serving to keep the content of the cultural transmission system fitness-enhancing and thus raising the fitness of individuals whose social-learning abilities are made possible by bias rules. Biased cultural transmission may invade an acultural population in the context of a fluctuating environment for the same reasons that individual learning is favored under frequent environmental variation: individuals who spend a certain amount of time and energy to develop the currently optimal phenotype, whether though individual learning or biased social learning, are at a fitness advantage. Hence biased transmission should be favored with increased environmental variability. Biased learning rules should provide the same opportunity for the spread of horizontal transmission structures as does individual learning.

However, if the exercise of biased learning rules is too costly or its results inaccurate, the former advantage will become a deficit. The prevalence of bias rules depends upon their cost and accuracy. Other things being equal, cheaper forms of bias are likely to be more widespread. This suggests that indirect bias rules, in which learners have only to register that a potential model for learning has some characteristic that is a correlate of fitness are likely to be more common among social learners than direct bias rules, in which oblige individuals to evaluate cultural variants on a costly case-by-case basis (Boyd and Richerson 1985:257, Flinn and Alexander 1982).

A final result, due to Boyd and Richerson, concerning biased transmission is relevant here. They offer a model of the evolution of direct bias rules in a population of unbiased social learners in a spatially variable environment. The model suggests that it is highly unlikely that genetically-controlled biases that are specific to certain habitats will evolve (1985:155-57). The conclusion gives theoretical justification to Alexander's conjecture that human learning rules will be universal among members of the species.

Although incomplete, the results summarized above on the evolution of cultural transmission are important because they offer theoretical guidance on several key issues, among them the conditions under which individual learning and biased transmission rules will be important. They indicate that if social learning is to be favored by natural selection, it must offer something that genetic transmission does not. Additional benefits arise in two contexts. When adaptive behavioral phenotypes can be learned socially but not acquired genetically, we can expect the evolution of vertical transmission structures that lack bias rules. Second, given that the same behavioral phenotypes are available to both individual and social learners, fitness benefits for cultural transmission are also available in the context of costly or error-prone individual learning rules in a moderately fluctuating environment. The models also indicate that horizontal transmission is only adaptive in the context of preexisting rules for individual social learning or biased transmission. Thus the importance of horizontal transmission in modern humans indicates that individual learning and biased transmission have had, and presumably continue to have, important effects on behavior.

The earlier discussion of learning rules indicates that they may be ranked on a continuum based on the costs associated with the generation and evaluation of variants. This continuum runs from individual learning at the high-cost end to directly biased cultural transmission to indirectly biased cultural transmission to unbiased cultural transmission at the low end. The higher cost learning rules only seem to be adaptive when environments fluctuate frequently. This suggests that if rules for individual learning and biased transmission are important determinants of behavioral phenotypes, they will determine those aspects of phenotypic variation for which the adaptively salient aspects of the environment shift rapidly and often. When environmental fluctuation is slower, a less costly, and probably less accurate, form of biased transmission, indirect bias, will be an especially pervasive form of phenotype determination. Individuals will acquire through unbiased transmission those aspects of phenotypes whose fitness values are affected by those aspects of the environment that shift even less frequently.

The practical implications of this theoretical result are enhanced by empirical evidence from primate field studies over the past two decades. Primates exhibit remarkable and adaptively appropriate facultative phenotypic flexibility in response to changes in their social environments. These include stochastic effects that affect demographic characteristics of small social groups like the availability of mates and the shifting makeup of coalitions that affect the reproductive success of participants (e.g. Dunbar 1988, de Waal 1987). Rates of fluctuations in such social conditions are likely to exceed those for many aspects of the non-social environment (e.g. food availability, predation risk). In fact, the contrast between the high level of skill exhibited by primates in social interactions and less impressive performance in the non-social domain have lead several authors to argue that primate "intelligence" is largely a result of selection acting in the context of the former (Jolly 1966, Humphrey 1976, reviewed in Essock-Vitale and Seyfarth 1987). In this context intelligence denotes behavioral flexibility based on costly (individual) learning rules. The models point to the importance of costly learning rules in the context of shifting environmental variables while the empirical evidence suggests those variables are social ones. The implication is that costly learning rules are likely to govern those aspects of interactions with conspecifics that have been adaptively important in a species evolutionary history, while less costly rules will govern interactions with aspects of the physical environment that typically change more slowly.

Taken together, the models show that operation of structural and bias rules will optimize genetic fitness relative to their absence or the presence of some alternative set of rules. However, this does not imply that all of the cultural variants transmitted in it enhance genetic fitness when considered individually. Some may be adaptively neutral. Others, as we saw earlier, may decrease fitness relative to alternative variants because of mistakes in the operation of learning rules. Although incomplete, theory already affords a rich array of possibilities for the casual dynamics behind phenotypic variation caused by individual and social learning. It suggests that bias forces will be important in the explanation of some culturally transmitted variation, but that cultural variation will also be subject to emergent forces, selection and drift, discussed in the previous section. The task of empirical research is to determine which forces apply in particular historical cases. In the next two chapters, I attempt to outline a version of the means to do this.

2.5 Conclusions

The dual-inheritance approach attempts to model the respective dynamics of genetic and cultural inheritance systems and interactions between them in a Darwinian framework. It combines models of cultural transmission under various structural and bias rules and models from neo-Darwinian population genetics. The result is an account of the origins of cultural transmission systems that have implications for the combinations of structural and bias rules that are likely to be found in species for which individual and social learning are important modes of phenotype determination.

The dual-inheritance program is an attempt to extend neo-Darwinian theory to provide explicit accounts of individual and social learning among all species, not just humans. Its relevance transcends the parochial interests of archaeologists or other students of human behavior. As the examples offered earlier in this chapter are meant to suggest, individual learning is widely spread throughout the animal kingdom and social learning is not unique to humans, although the extent of its importance among humans might be. Dual-inheritance theory thus offers a constructive means of addressing deficits in the sociobiological research program that is not based on the notion that humans have unique behavioral capacities that make evolutionary theory irrelevant to constructing accounts of human behavioral variation. This last proposition, dear to many critics of sociobiology, is especially pernicious for two reasons. It effectively removes human behavior from the realm of scientific discourse. It perpetuates the notion that individual and social learning are irrelevant to accounts of non-human behavior.

The connection to evolutionary biology should be especially congenial to archaeologists, given the large amounts of time and space encompassed by the archaeological record. The domain of study includes hominid evolution from the appearance of the first stone tools. A dual-inheritance approach offers the promise of a single unifying framework in which to understand the interacting biological and cultural aspects of evolutionary history of hominids with wildly different cultural capacities that stretches over the past two million years. Nor are the advantages of a dual-inheritance approach limited to the far reaches of the prehistoric past. An expanded evolutionary theory offers a mechanistic account of decision making (guided variation) and choice (direct bias) that many anthropologists insist must be treated in terms of the manifest image. Understandings in terms of human dispositions are fundamentally incomplete and hence suspect unless we can offer an evolutionary account of the processes leading to the fixation of the rules that underlie them. The requirement that such explanations ultimately be tied to a Darwinian framework constrains and guides theoretical innovation. It encourages consistency with a progressive and successful scientific research program. It prevents the ad hocism that characterizes uncontrolled speculation about the essences of human and human history which the manifest image encourages. The approach thus promises a progressive and cumulative understanding of the manner in which both genetic and cultural conditioners of human behavior have evolved.

My goals in the following chapters, however, are far more modest, requiring only simple versions of models of cultural transmission developed recently by Boyd and Richerson and Cavalli-Sforza and Feldman. In the next chapter I explore in more detail the dynamics of cultural systems governed by various structural and bias rules, along with the effects of the operation of the emergent forces drift and selection operating of cultural variants. In other words, I present some simple versions of the force descriptions and consequence laws that might form the foundation for a cultural evolutionary theory that would be useful in archaeological inference. At this juncture, it might be wise to emphasize this last point. Much of this and the previous chapter has been theoretical. The reason for worrying about theory is that it will, with luck, eventually prove be *useful* in making inferences about phenomena. The next chapter provides the tools to further that pragmatic goal in two ways. From the models can be derived generalizations about temporal patterning generated by various cultural evolutionary forces. The hope is that patterns generated by models will prove useful in diagnosing the evolutionary processes behind patterns documented in the archaeological record. Second, the models allow additional clarification of the way in which evolutionary theory figures in the functional-morphological approach to archaeological inference described in Chapter 1.

Chapter 3

Some Simple Models of Cultural Evolution

3 Introduction

As we have seen, much of what is considered middle-range theory in recent archaeological literature can be read as an attempt to establish source laws for deterministic forces that might sort cultural variants. In this chapter I emphasize what I have argued are the more fundamental components of evolutionary theory. These are the zero-force state, force descriptions, and consequence laws. The former defines the character of the system under study, while the latter pair make possible depictions of system trajectories as various forces impinge upon it. My treatment of forces is not limited to those that cause the deterministic sorting of variants, but also includes forces that introduce variation and stochastic sorting, a cultural analogue of genetic drift.

There are several motivations for reviewing these simple models of cultural evolutionary process. First, they make it possible to generate expectations concerning the properties of temporal trajectories of cultural variants under different forces. These expectations can be used to make inferences about the kinds of processes responsible for temporal variation in the archaeological record. Second, they will allow us to answer in an evolutionary framework questions raised in Chapter 1 about the theoretical grounding of the functional-morphological approach to archaeological inference. Finally, as we shall see in later chapters, explicit consideration of consequence laws will help in the generation of source laws applicable to different sorts of historical circumstances.

3.1 Zero-force and Consequence Laws for Cultural Transmission

As I suggested in the previous chapter, cultural transmission should be understood as the transfer of information from one individual to another by teaching or imitation. The information transferred can be considered instructions or rules for behavior. The rules specify how particular behaviors are to be executed and the circumstances under which those performances are appropriate. Transferred information may also include culturally specified rules for individual and social learning.

The models that follow are couched in terms of alternative instructions concerning some aspect of behavior. I will refer to these alternative instructions as cultural variants or forms. Alternative cultural variants will be modeled as the values of discrete variables. Continuous treatments are possible and have been developed for most of the cases discussed below by Boyd and Richerson (1985). I have chosen discrete traits here because they are simpler to work with, and because archaeologists have tended traditionally to measure the properties of the archaeological record on discrete scales (Dunnell 1986b).

The notion of culture as socially learned information has much in common with the traditional archaeological notions developed by culture historians that called attention to the fact that similar artifact forms appeared in adjacent times and places because they were the product of shared ideas (e.g. Rouse 1939:15-18, Taylor 1949:101, Ford 1954:47). It is also found in the work of archaeologists who take the accomplishments of culture history seriously (e.g. Dunnell 1971:121-122, Deetz 1965:64).

There is, however, a second anthropological tradition that glosses culture as beliefs, behavior, and the artifactual products of behavior. It is found in Binford's formulation of the new archaeology (1972:198) and Harris' cultural materialism (1979:136), derived in both cases from the work of Leslie White and, ultimately, Tylor. An attack on what was called culture history's "normative" conception of culture was an integral part of the New Archaeology's polemic (Binford 1965). Despite the rhetorical cast, the critique did point to a real flaw in culture history's use of culture as an explanatory concept. This was its habit of characterizing cultural historical units, phases for example, in terms of isolated traits, rather than describing them as the product of functioning societies or cultural systems. The problem was given concrete expression in the functional variability debate where culture history was taken to task for operating with interpretive conventions that would incorrectly gloss functionally diverse occupations generated by a single social group as the products of multiple, ethnically distinct groups (e.g. Binford and Binford 1966). The critique was powerful and ended the intellectual respectability of the trait-list approach. However, it also damaged the respectability of the notion of culture as information. It important to see, however, that the trait list approach has no necessary link to any particular view of culture. As we have seen in the previous chapter, social learning is a form of phenotypic flexibility. Hence we can expect the behavior generated by cultural rules to be situationally variable.

The distinction between culture and behavior is essential to an evolutionary approach. It does not, as Binford mistakenly has argued, commit one to a "mentalist explanation for variability in behavior" (1981:202). In fact, it is the foundation for a completely mechanistic account of the differential persistence of behavioral phenotypes in time and space. Without the culture-behavior distinction, it becomes impossible to provide an account of the causal mechanisms responsible for the fact that individuals exhibit behavioral variability on the large temporal and spatial scales that are typically the subject of archaeological inquiry (Hull 1980:320, cf. Marks and Staski 1988), unless one is willing to insist that absolutely all behavioral variation is the product of genetically-guided individual learning. This is not to deny, however, that important components of archaeological variation are linked to behavior driven by context-sensitive rules for behavior within a single population.

If the culture-behavior distinction is fundamental, it also raises two important issues whose satisfactory resolution lies in the future: how precisely is information transmitted and stored and how is information transformed into behavior? Current knowledge of transmission mechanisms and the rules for social learning that describe their operation is analogous to pre-Mendelian treatments of genetic inheritance. We simply do not know very much about the ranges of parameter values for structural and bias rules that control how social learning proceeds. Do learners pay more attention to some models than others when acquiring new information? How many models do learners observe before learning occurs? What happens when models conflict? There is a dearth of solid empirical guidance on these matters. Perhaps more discouraging is the fact that socio-cultural anthropologists, whose interest in contemporary cultural diversity might make them ideal gatherers of this sort of information, exhibit absolutely no interest in such matters (cf. Hewlett and Cavalli-Sforza 1986). In this situation, the only course is to make models that are flexible and general enough to include an array of plausible possibilities. Clearly, improved knowledge on these topics would contribute enormously to the power of an evolutionary approach to social learning, just as the incorporation of Mendelian genetics into Darwinian theory strengthened it (Provine 1971).

The culture-behavior distinction suggests that the relationship between behavioral rules and the performances they engender is analogous to the more strictly biological distinction between genotype and phenotype described by developmental genetics. As in the biological case, just how a particular cultural instruction receives behavioral expression may depend upon environmental circumstances. This is most apparent where an individual's ability to perform certain behaviors depends upon access to resources. It has only been in the past decade that there has been much progress in beginning to understand the biochemical processes by which DNA builds organisms. The analogous knowledge of the neurophysiological mechanisms by which cultural information is organized and stored does not exist. Nor is much known about the way in which information is subsequently translated into behavior. In the face of such ignorance, cultural evolutionary models must rely heavily on the presumed existence of simple correlations between cultural and behavioral variants if they are to be used to account for behavioral variation. In other words, it is assumed that within a population of social learners confronting similar environments, cultural instructions that are copies of a common ancestral cultural instruction will cause their bearers to exhibit recognizably similar behavioral phenotypes.

The previous chapters may seem to have offered evolutionary theory as a panacea for archaeology's theoretical ills. However, as the foregoing comments should suggest, I have no illusions about the difficulties fostered by any attempt to incorporate evolutionary thinking into archaeological theory. The two problematic areas mentioned above characterize cultural evolutionary theory in general. Advances in these areas, if they are forthcoming, will not be made by archaeologists working by themselves. There is, however, a third problem, whose resolution is more uniquely archaeological, that also deserves mention here. The dual-inheritance approach has its foundations in the scholarly tradition that is responsible for the consequence laws of evolutionary theory: population genetics. The laws of population genetics are written in mathematics. The mathematics is hard, so hard in fact that it is increasingly the province of applied mathematicians. Not unexpectedly, much of the modeling produced involves mathematical sophistication well beyond the grasp of most archaeologists, including me. This set of circumstances may prove to be a major stumbling block to the adoption of an evolutionary research program in archaeology. Over the long term, it will require major adjustments in the background that students of archaeology bring to the subject. In this chapter, I am forced to content myself with the simplest, and thus least realistic, versions of the models of cultural transmission. However, I believe even these stylized treatments offer a more rigorous understanding of the processes and dynamics of cultural transmission.

None of these problems should be minimized. On the other hand, the arguments I have presented in the previous chapters concerning the need for theory development in archaeology suggest that there is something to be gained by the attempt to incorporate in an explicit way even incomplete and simplistic consequence laws into archaeological inference.

3.2 Zero-force State

In Boyd and Richerson's treatment, the zero-force state for social learning contains three components. The first is stipulation of the structural rules of the transmission system that specify the background conditions of the inheritance system, analogous to the rules of Mendelian inheritance in the genetic case. The second and third components represent the *absence* of two broad classes of forces that might affect the frequency of cultural variants in the population over time. These are the various forms of biased transmission and the emergent forces, selection and drift.

The background conditions that comprise the first component of the zero-force model are specified as follows. First consider vertical and oblique transmission, that is transmission from members of one generation to members of the next generation, in a very large population of social learners. Each individual is characterized by one of two mutually exclusive cultural variants that can be labeled c and d. The (relative) frequencies of c and d in the population are p and 1-p. As one generation replaces another, each new individual is enculturated by m models or cultural parents, comprising a model set. We can allow for the possibility that the m models have characteristically different influence on the transmission process by assigning them different weights. Thus the weight of the i'th model, for i=1...m, is A_i which gives the probability that the learner acquires its cultural variant from that model. The A_i must sum to unity. That is, transmission must take place. The weights represent the possibility that individuals learn from individuals who occupy different social roles that in turn have characteristically different influence on the learning process. Thus mothers might be more influential than their sisters in teaching daughters agricultural techniques. Note that the importance of social roles may vary for different kinds of traits.

The second component is the representation of the unbiased transmission rule that specifies what happens when a learner encounters M models. This rule gives the probability that the learner acquires variant c, given that the learner has been exposed to a set of m models having a particular permutation of cultural variants. The first two panels of Table 3.1 give an example of an unbiased transmission rule for two models. With two models and two variants, there are four possible combinations of models or model-set types. More generally, for two variants the number of model-set types is 2^m. The model-set types are analogous to the mating types found in genetics (Cavalli-Sforza and Feldman 1981:78).

Model-set Types		Probability Learner Acquires Variant		Probability Model-set Type is Formed
Model 1	Model 2	c	d	
c	c	1	0	p^2
c	d	A_1	A_2	$p(1-p)$
d	c	A_2	A_1	$(1-p)p$
d	d	0	1	$(1-p)^2$

Table 3.1. Cultural transmission of a dichotomous trait with an unbiased, linear transmission rule and random formation of model sets comprised of two models.

Note that the transmission rule can be specified in a somewhat more compact fashion if we let the two cultural variants, c and d, be represented by numerical values 1 and 0. If X_i is the numerical value of the i'th model in a particular model set, then the probability that a learner acquires cultural variant c from a set of models, given that the models have the values $X_1,...,X_m$ is

$$\text{Prob (learner=c} | X_1,...,X_m) = \sum_{i=1}^{m} A_i X_i \qquad (3.1)$$

where the A_i are the weights of the M models. This quantity is simply a weighted average of the values of the models. As in Table 3.1, if both models are c, that is X_1 and $X_2 = 1$, then the probability the learner acquires c is unity. If both models are d, it is zero (Boyd and Richerson 1985:66).

The transmission rule specifies the probability that a learner becomes c, given that the learner encounters each of the possible model-set types, but we still need to know how likely each encounter is. This is the third component of the zero-force law that depicts the manner in which the model sets are formed. In analogy with the random mating assumption behind Hardy-Weinberg, we stipulate that the model sets are formed at random before transmission occurs. This implies that whether individuals are c or d does not affect their chances, averaged over all possible model-set types, of becoming models, or their chances of becoming models with a particular weight. Under random formation of model sets, the probability that a given learner encounters each of the model-set types is given in the third panel of Table 3.1. It is simply the product of the frequencies of the variants that characterize each of the models in the set. Random formation of model sets containing m models can be expressed more generally for any number of cultural parents using the algebraic notation introduced above. The probability that any model set with m members, I of whom are c, is formed is

$$M(X_1 X_2 ... X_m) = p^I(1-p)^{m-I} \qquad (3.2)$$

The transmission rule gives the probability that a learner acquires variant c, given that the learner is confronted with a model set of a certain type. The model-formation component yields the probability that a given model-set type is formed. The unconditional probability that a learner acquires variant c from a model-set type is simply the product of these two probabilities. The overall probability that a learner acquires c in the next generation, is then obtained by summing all the unconditional probabilities associated with all possible model-set types. Combining the transmission rule and the model formation scheme for two models yields the following expression for p′, the frequency of c in the next generation (Boyd and Richerson 1985:64-66):

$$p' = (1)p^2 + A_1p(1\text{-}p) + A_2p(1\text{-}p) + 0(1\text{-}p)(1\text{-}p) \qquad (3.3a)$$

$$p' = p^2 + (A_1 + A_2)p(1\text{-}p) \qquad (3.3b)$$

Since the weights sum to 1,

$$p' = p \qquad (3.3c)$$

This very simple model might represent cultural transmission from 2 parents to their children, or from one parent and a genetically unrelated member of the parental generation, or from two unrelated individuals. It is worth noting that when the weights are equal, the model is equivalent to treatments of genetic transmission for haploid organisms in which every genetic variant can only be represented in an organism once (Cavalli-Sforza and Feldman 1981:83-85).

This same model can be expressed in an initially more formidable yet also more general form that makes use of the algebraic formulation of the unbiased learning rule:

$$p' = \sum_{X1=0}^{1} \sum_{X2=0}^{1} \left(\sum_{i=1}^{m} A_iX_i \right) M(X_1\ X_2) \qquad (3.4)$$

The first term is the linear transmission rule that gives the probability a learner acquires c from a particular combination of models. The second represents the probability that each of those combinations is formed. The double summations specify that these two terms are to be summed over all possible combinations of models. A generalization of this simple model in the form of 3.4 to three or more cultural parents and a more relaxed mating scheme that includes the possibility of assortative formation of sets of models is provided by Boyd and Richerson (1985:66-67). They also offer a parallel treatment for continuously varying cultural forms, under the assumption of blending inheritance, where learners derive their cultural variants by averaging behavioral values displayed by their models.

The model presented above is cast in terms of vertical and oblique transmission. The primary modification required for its application to horizontal transmission is conceptual (Boyd and Richerson 1985:68-69). Again we consider a population of individuals each of whom is characterized by variant c or d. During some time interval, delta t, each individual encounters m-1 other individuals. These other individuals, along with the learner himself, are the models or cultural parents comprising the model set. At some time, t+delta t, each individual adopts the cultural variant of the i'th model with probability A_i. This implies that each learner retains his old cultural variant, that is, learns from himself, with probability A_1. Conservatism on the part of learners is represented by values for A_1 close to one. Thus the transmission rule has exactly the same form as Equation 3.1. The formation of models component remains formally unchanged as well. To see this consider the probability that any model-set type is formed under the vertical scheme. For example if the first model is c and the second is d, this probability is $M(X_1=0,X_2=1) = (1-p)p$. In both the vertical and horizontal cases, the second term, p in this case, represents the probability that a randomly chosen second model is c. The first term, 1-p, is the same in the two cases since the probability of randomly choosing a carrier of d in the vertical scheme equals the proportion of learners who are d in the horizontal case. Hence, if each individual enters a model set as the first model and the remaining m-1 models are sampled from the population at random, the frequency of c remains unchanged.

This result means that treatments of the operation of evolutionary forces developed for vertical and oblique transmission structures, on the one hand, and horizontal ones, on the other, are interchangeable with little modification. Successive time periods in the former case are generations, while in the latter they become the amount of time required for an individual to learn a new cultural form with probability A-1. It is worth noting that this equivalence does not extend to many of the models of oblique and horizontal transmission developed by Cavalli-Sforza and Feldman (1981:131,151) in which the treatment of alternative cultural variants is not symmetrical, that is one variant is more likely to be transmitted than another (Maynard Smith and Warren 1982). In other words, the base-line models of Cavalli-Sforza and Feldman for horizontal and oblique transmission incorporate the operation of a force: direct bias.

The results of all these exercises are the same. When transmission is characterized by the absence of any bias forces and when the formation of sets of models is non-selective, the frequency of the cultural variants in the population remains unchanged. This zero-force state for cultural transmission essentially defines the way in which phenomena are conceived. Inquiry is about the differential persistence of cultural variants in time and space. However, this does not imply that when a lack of change is observed in the real world, no explanation is required. As we shall see, forces of one sort or another are always at work. Having established zero-force state we can proceed to the enumeration of forces that operate to alter or stabilize the distribution of cultural variants in successive generations or time periods. Below I discuss first forces that introduce variation into a population of social learners, random variation, guided variation and migration. I then turn to the forces that in certain circumstances deterministically sort it: direct bias, indirect bias and selection. Finally, I consider stochastic sorting.

3.3 Guided Variation

The first force, which following Boyd and Richerson I will call guided variation, represents the effects of individual learning in a cultural transmission system. Recall from the previous chapter that individual learning is underlain by a set of learning rules. The rules enable individuals to associate an initially neutral behavioral variant with the effects of that variant in a given environmental context and to evaluate those effects as good or bad. Individual learning is a likely precursor to the evolution of cultural transmission. When combined with cultural transmission, it effectively generates a force that alters the frequency of cultural variants in later generations. We can see exactly how with a simple dichotomous-variant model. For a continuous treatment, the reader is referred to Boyd and Richerson (1985:95 ff.). Consider an individual operating in an altered environment with a set of rules for individual learning. The combination of the environment and the rules determines the probability that the individual will learn through his individual efforts the behavioral variant, c, which is optimal in terms of the structure of the transmission system that fixed the rule. However, as I have emphasized, systematic errors are also possible.

For a simple two-variant model, let c represent the optimal variant and d represent the alternative. First consider a population without cultural transmission. When individuals are born into the population, they acquire their mature phenotypes by using the learning rule. The successful operation of the rule in a given environment is represented by r_c, the probability that individuals learn the optimal variant before they become adults. The error rate implied in this formulation is $(1-r_c)$, the probability that individuals using the learning rule learn the alternative variant. If there is no cultural transmission, the frequency of c among mature individuals at the end of each generation is simply

$$p = r_c \tag{3.5}$$

In other words, without cultural transmission the frequency of c among mature individuals from generation to generation is constant.

Cultural transmission can be added to this simple model by allowing the knowledge gained about the optimal variant by one generation be transmitted to the next. Now individuals acquire their initial phenotype by vertical and oblique transmission from the previous generation. They then modify their phenotypes in accordance with 3.5. However, in this case the error rate becomes the probability (r_d) that individuals who initially acquired the optimal variant by cultural transmission mistakenly learn the alternative using the learning rule. Having used the learning rule to modify their culturally inherited variant, mature individuals then become models for the next generation. Under this scheme, the frequency of c in the next generation is

$$p' = p + (1-p)\, r_c - pr_d \qquad (3.6)$$

Although originally cast in terms of vertical and oblique transmission, the model is easily applied to horizontal schemes. As in the derivation of the zero-force law, we simply let the generation time equal the amount of time it takes for each individual to learn from others with some probability $1-A_1$, where A_1 is the probability that individuals serve as their own models. The two parameters r_c and r_d become the probability that optimal variants or errors respectively result from the use of the learning rules during that period.

In most cases, the rules for learning will function effectively enough to guarantee that r_c is much greater than r_d. When this is true and cultural transmission is combined with individual learning, the frequency of c increases in successive generations. When c is rare, the rate of increase, governed largely by the second term in 3.6, is greatest. As c becomes more common, the second term assumes increasing importance and the rate of increase slows. Eventually the frequency of the favored variant in the population will stabilize at an equilibrium value computed from 3.6 by setting $p' - p$ equal to zero and solving for $\hat{p}$.

$$\hat{p} = r_c / (r_c + r_d) \qquad (3.7)$$

Figure 3.1 shows the trajectory of change under guided variation, according to 3.6. Note that modest values of r_c lead quickly to equilibrium values of c in the population. Note too that change in the frequency of c does not depend on the initial existence of variation in the population. In other words, change occurs even if the starting frequency

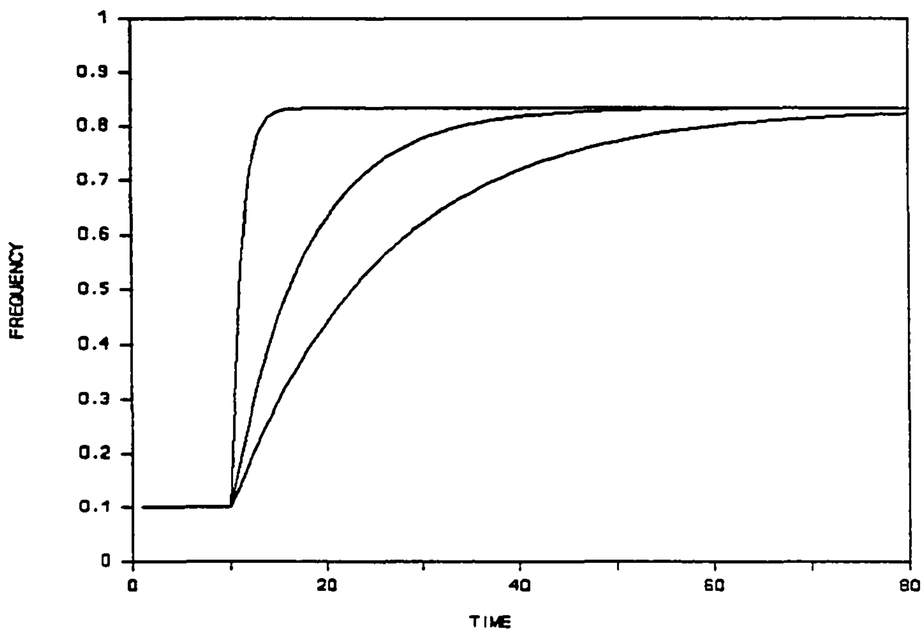


Figure 3.1. Change in c under guided variation for various parameter values: $r_c=.05$, $r_c=.1$, $r_c=.5$. The error rate is constant fraction of r_c: $r_d=.2r_c$. Operation of the learning rule begins at $t=10$.

of c is zero. This is merely another way of saying that guided variation introduces new forms to a population. It does not sort pre-existing ones.

3.4 Random Variation

Random variation is the second means by which novel cultural variants are introduced into a population. The process is analogous to genetic mutation and "random" is to be understood as it is in the genetic context. Novel variants are undirected with respect to the adaptive requirements of the individuals whose phenotypes they help build. Environmental shifts do not bring onto existence variants that are more likely to be adaptive under new conditions than under former ones (Vrba and Eldredge 1984:155, Campbell 1974:422). In general terms, this means that variants are not preferentially generated that will be favored by the deterministic processes that sort variants. Thus while genetic variants may be constrained in variety and even biased in one direction (mutation pressure), they are produced without respect to neo-Darwinian fitness differences among them. Similarly in the cultural case, random variants are those novel forms whose generation is unrelated to what will be favored by selection in operating in a possibly asymmetric transmission system.

There are several plausible mechanisms that might introduce undirected cultural variation into a population. Learners may erroneously perceive or encode for storage in memory the behavioral variant of their models. Errors may also creep into the stored information so that it is either forgotten or incorrectly recalled at a later time. The behavior prescribed by the learning rule may be incorrectly performed by individuals serving as models for others (Boyd and Richerson 1985:67-68). Finally, the cognitive activities, which common sense optimistically glosses as planning or problem solving, may be simply mechanisms for the production of variants that are undirected or random with respect to their adaptive consequences.

It is easy to build a model of random variation for a dichotomous cultural trait. It is identical to the elementary population-genetic treatment of mutation (Wilson and Bossert 1971:42-44). Suppose that μ_a is the probability that an individual erroneously learns, remembers or transmits cultural variant c as d in a single generation and μ_c is the corresponding error rate for d to c. The frequency of c after one generation is

$$p' = p + (1-p)\,\mu_c - p\mu_d \tag{3.8}$$

The equation, along with its equilibrium and its horizontal analogue, is formally identical to those for guided variation presented above. The formal identity should not be surprising since both forces result from the production of novel variants within individual members of a population. On the other hand, there are two important substantive differences. The first I have noted above: variants generated under guided variation are likely to be adaptive in the context of the inheritance system in which the learning rule that generated them was fixed. The second difference is a consequence of the very different parameter values that characterize each process. The rate at which individuals discover the optimal variant (r_c) under guided variation is likely to exceed by orders of magnitude the rate at which errors lead to the creation of any particular novel undirected variant (μ_c). This is simply because the former process is guided, while the latter is not. The contrast has important consequences for evolutionary dynamics. As a glance at Figure 3.1 should demonstrate, guided variation not only introduces variation intc a population, it eventually destroys it. If the learning rule whose operation is captured in r_c is powerful in relation to other evolutionary forces, it may eliminate any variation from the population before those other forces have a chance to sort it. The formal identity of 3.6 and 3.8 reminds us of the possibility that random variation might have a similar effect. The reason that it does not lies in the fact that the pressure (μ_c) favoring any particular randomly generated variant will be very weak in comparison to the forces operating to increase or decrease its frequency via sorting.

A second aspect to the relationship between guided and random variation deserves attention. There is a sense in which random variation underlies all learning processes (Campbell 1965, 1974, Plotkin and Olding-Smee 1981). On this construction, guided variation should be understood as a two-part process that begins with random variation. In the first part, undirected variant behavioral instructions are generated within an individual, either fortuitously or through the operation of a learning rule whose operation may be invoked by environmental perturbations. In the second component, additional learning rules sort these variants on the basis of an evaluation of their consequences. This algorithm is present at a variety of levels in the biological world. For example, the initial behavioral gambits that are part of associational learning -- the rat's initial decision to taste of novel food -- can also be considered undirected variants, which are later selected on the basis of their consequences by learning rules. Rational calculation and decision making made possible by complex cognitive abilities can be glossed similarly. Here the generation of random variants and their selection on the basis of their consequences all take place in an individual's brain. This perspective does not imply that random variation is guided variation. Rather it helps isolate the difference. Guided variation is different because learning rules may dictate the timely generation of undirected variants that in turn are sorted by other learning rules before they are incorporated into the cultural repertoire and thence the behavioral phenotype of the individual with whom they originated. Guided variants have been "pre-selected" before they can be culturally transmitted to others (cf. Boehm 1978).

3.5 Migration and Indirect Transmission

Migration is the third force responsible for the introduction of novel cultural variants into a population. The arrival of immigrant individuals may have an effect on a population similar to random variation, although the amount of variation introduced through migration is potentially far greater. Migration from several donor populations to a recipient population can be modeled in a simple way as follows (cf. Cavalli-Sforza and Feldman 1981:157-159). The treatment closely parallels simple models of migration or gene flow found in population genetics (Wilson and Bossert 1971:46-47, Crow 1986:58). Consider three populations. P_1 is the recipient population and P_2 and P_3 are the donors. Let p_1 be the frequency of cultural variant c in P_1 and p_2 and p_3 be the frequency of c in P_2 and P_3 respectively. During each time period, a generation in the case of vertical and oblique transmission, P_1 receives some proportion m_2 of its population from P_2 and proportion m_3 of its population from P_3. Under these conditions the frequency of c in P_1 after one period of migration is given by

$$p_1' = (1-m_2-m_3)p_1 + m_2p_2 + m_3p_3 \qquad (3.9)$$

The term $(1-m_2-m_3)$ represents the proportion of P_1 who are not immigrants. Hence the frequency of c in P_1 is simply an average of the frequency of c in each population weighted by their contributions. If the process is allowed to continue long enough with constant migration coefficients (the m terms), an equilibrium is reached at which

$$\hat{p}_1 = (m_2p_2 + m_3p_3)/(m_2 + m_3) \qquad (3.10)$$

Eventually the frequency of c in P_1 is an average of the frequency of c in the two donor populations, weighted by their contributions. Figure 3.2 shows the trajectory of change expected in the composition of the recipient population for several values of m coefficients. It is evident that relatively modest values for m lead to large changes in the composition of the recipient population if the donor populations are different from it. If values for m are large, the change is very rapid. One degenerate case is worth mentioning. The model can be applied to population movements in which immigrants either replace or displace what might have been a recipient population. Here the migration coefficients sum to one, that is all members of P_1 in the first time period are derived from outside populations. The equilibrium is reached instantaneously.

Migration models of this sort cover cases in which the movement of cultural traits from one population to another is accompanied, indeed caused, by the movement of individuals. However, a similar result is produced when cultural traits are transmitted via artifacts. The process can be called indirect transmission, to emphasize that it does not require direct contact between individuals from different populations. (cf. Cavalli-Sforza and Feldman 1981:158). Indirect transmission occurs in several ways. Among them is the movement of artifacts through "down-the-line" exchange among populations. When artifacts are passed successively among local groups, group members may learn construction and design information without having had any face-to-face contact with the exchanged artifacts' makers. With the advent of writing systems, similar effects will result from the movement of documents among populations. The evolutionary consequences of the mass distribution of cultural information in printed form can be enormous. If a given population has exclusive access to the production of documents or other information media that are disseminated to other populations, then indirect transmission will cause variant frequencies in the latter populations to become identical to those in the former, if no other forces intervene.

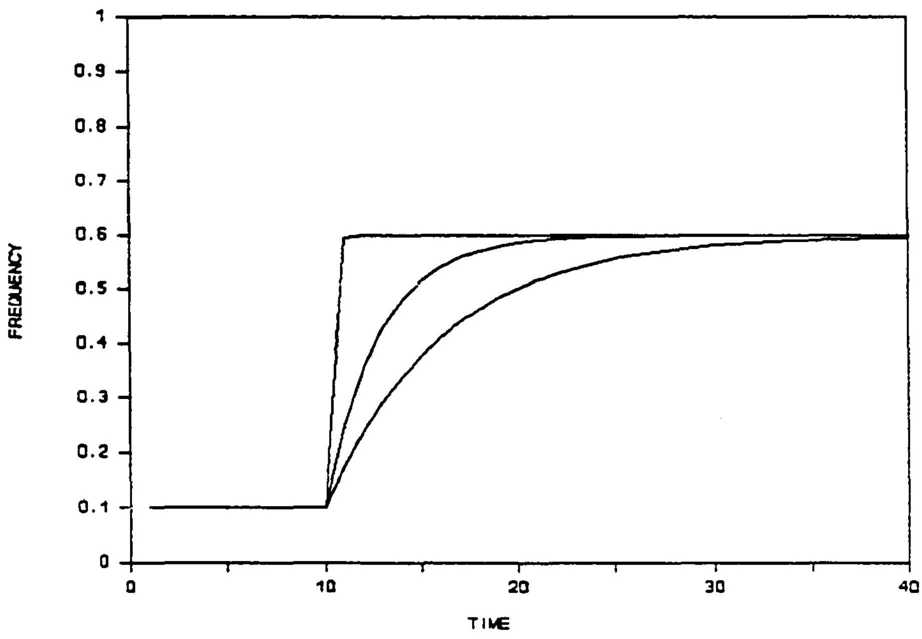


Figure 3.2. Migration from populations P_2 and P_3 to P_1 for migration coefficients m_2=.05, m_3=.1; m_2=.1 m_3=.2; m_2=.33, m_3=.66. Initial frequencies of c p1=.1, p2=.2 and p3=.8.

To see this, consider the following simple model for horizontal transmission for a dichotomous trait. There are two populations, P_1 and P_2, the former with media access, the latter without. We let p_1 and p_2 represent the frequency of variant c in the two populations. In each time period, learners from P_2 encounter M models or sources for cultural information. There are two kinds of sources, other members of P_2, including the learner, and artifacts that are derived from P_1. We let m_1 be the proportion of information sources that are artifacts. Thus 1-m_1 is the proportion of sources that are individuals from P_2. For example P_2 might be comprised of 90 individuals, 10 of whom possessed books, containing prescriptions for the cultural trait values derived from P_1.

Thus $m_1 = .1$. During each time period, individuals learn from themselves with probability A_1 and from other sources, other individuals or artifacts, with probability $1\text{-}A_1$. Under these conditions the frequency of c in P_2 in the next time period is given by:

$$p_2' = A_1 p_2 + (1\text{-}A_1)(p_2(1\text{-}m_1)+p_1 m_1) \qquad (3.11)$$

The dynamics generated by this equation are similar to those we have covered under migration, only here the effect of indirect transmission is diluted by the tendency of individuals to retain their old cultural variants, represented by A_1. When $A_1 = 0$, that is when all individuals learn from others during each time period, 3.11 is identical to a version of 3.9 for two populations.

3.6 Direct Bias

I now turn from forces that introduce new variants into populations to forces that sort cultural variation in a deterministic fashion. I first consider the operation of bias rules mentioned in the previous chapter. I review Boyd and Richersons's simple models for direct bias in this section and offer a simple treatment of indirect bias in the next. A start at understanding bias rules can be had by comparing their operation to unbiased transmission, that is to the zero-force state outlined above. Once the structure of the transmission system had been specified, the zero-force law had two components. Models or cultural parents were chosen at random such that the frequency of variants represented among all model sets matched the frequency of variants in the population at large. In addition, the variant transmitted to a learner was chosen at random from those carried by members of the model set, once the weights that each of the models brought to the transmission process were taken into account. Violations of the first component of the zero-force law constitute what I have termed the emergent forces: selection and drift.

The different varieties of biased transmission violate the second aspect of the zero-force law. Under biased transmission, some variants among those represented in a given set of models are disproportionately likely to be learned, regardless of the model's initial weights. In other words, bias rules tell learners which variant they should choose from those offered.

All bias rules are attempts by organisms to evaluate variants before adopting them. The means to do this are variable. All involve learning rules that are designed by selection to increase the chances that the variant adopted will be adaptive in the context of the transmission system that fixed the rules. Direct bias represents attempts by individuals to evaluate cultural variants on the basis of their own merits. Individuals may do this by experimenting with novel variants, observing their effects and evaluating them, either in the real world or in their brains, or by observing the effects of the variants in the behavior of others.

The exercise of direct bias requires that individuals possess learning rules similar to those which underlie individual learning. Direct bias rules enable individuals to identify the effects of a set of alternative cultural variants, evaluate them on some scale, and then choose to adopt the optimal variant. Despite the fact that the rules that individuals use in the exercise of direct bias and guided variation may overlap, the distinction is important in evolutionary terms. Under direct bias, variants are offered to learners by the sets of models they encounter. Learners become aware of variants because they are culturally transmitted. Under guided variation, as we have seen, individuals generate their own variants, which they may use to modify their behavioral phenotypes. Only after variants have been incorporated into an individual's phenotype are they subject to cultural transmission. Bias sorts pre-existing cultural variation. Individual learning generates it.

In order to build a simple model of direct bias we proceed as follows (Boyd and Richerson 1985:137-141). Once again there are two variants, c and d, the former favored by direct bias, the latter not. During each time period, learners are enculturated by model sets comprised of two cultural parents. As before, the models are biological parents under vertical transmission or peers, including the learner himself, under horizontal transmission. The effects of direct bias can be represented by B, the bias parameter. The bias parameter portrays the outcome of the use of bias rules to evaluate alternative variants. It is the proportion by which the probability that a learner acquires the favored trait is raised and by which the probability that the learner acquires the unfavored variant is lowered, given that both variants are represented among the learner's set of models. This formulation makes explicit an important feature of direct bias: direct bias only operates in transmission systems based on structural rules that allow learners to have more than one model or cultural parent in each time period. Within such systems, direct bias only affects transmission when more than a single variant is present among a learner's models.

Since direct bias leaves the formation-of-model-sets component of the zero-force law unchanged (3.2), we need only modify the learning rule (3.1). A simple way to do this is to let the cultural variant of a model change the probability that the learner learns from him. This means that the importance of a model must now be a function of not only his initial weight, the A_i of 3.1, but also of his cultural variant. A first step is to define the function:

$$\beta(X_i) = \begin{cases} B \text{ if } X_i = 1 \\ -B \text{ if } X_i = 0 \end{cases}$$

We now adjust the influence of the i'th model in a particular model set as follows:

$$A_i' = \frac{A_i\,(1 + \beta(X_i))}{\Sigma_{j=1}^{m} A_j\,(1 + \beta(X_j))} \qquad (3.12)$$

The numerator is the raw adjustment of the weight of the i'th model. That weight is raised by a factor of (1+B), if the model carries variant c, and is lowered by a factor of (1-B), if the model carries variant d. In other words, the numerator captures the essence of direct bias: whether or not a model is imitated should depend on its cultural variant. Note that the value of B lies between 1 and 0 since the weights must be positive. The denominator sums the similarly adjusted weights of all the models in the set. The division by it normalizes the weights, forcing the A_i' to sum to unity. Thus the learning rule for direct bias has the same form as 3.1, except the A_i in 3.1 are replaced by A_i' derived from 3.12. Since the learning rule for direct bias is non-linear, a completely general model for direct bias that accommodates variable numbers of cultural parents with variable initial weights is difficult to analyze. I therefore present two simpler models for special cases, one for two cultural parents with variable weights and one for variable numbers of cultural parents with equal weights. These will allow us to see how change in the frequency of forms favored by direct bias is affected by these two factors.

Consider first the case in which individuals encounter two models and learn from them according to 3.12. Here again the model is equally applicable to vertical-oblique and horizontal transmission schemes. The frequency of variant c in the following time period can be had by simply substituting the A_i' for the A_i in 3.3. This yields:

$$p' = p^2(1)+p(1-p)\frac{A_1(1+B)}{A_1(1+B)+A_2(1-B)}+(1-p)p\frac{A_2(1+B)}{A_1(1-B)+A_2(1+B)} \qquad (3.13a)$$

Taking advantage of the fact that the initial model weights sum to one, this can be simplified to

$$p' = p + p(1-p)\frac{4BA_1A_2}{1-B^2(A_1-A_2)^2} \qquad (3.13b)$$

Note that the amount of change in the frequency of trait c in a given time period is given by the second term on the right hand side of 3.13b and is therefore a function of three quantities. Not surprisingly, one of them is B. As the strength of direct bias in favor of a cultural form increases, so does the rate of evolution. The second quantity represents the amount of variation in the population, that is the variance of p, given by p(1-p). When the variance in the population is greatest, $p=.5$, so is the rate of increase in the favored trait. This is the formal manifestation of the point that direct bias sorts pre-existing variation. If there is no variation -- the variance of p is 0 -- direct bias has no effect. As a result, the temporal trajectory of p starting from low frequencies is sigmoid (Figure 3.3). These two determinants of the magnitude of the force exerted by direct bias on a population are most transparent in a simplification of 3.13b. That simplification is possible if one assumes that the initial weights of both models are equal, $A_1 = A_2 = .5$. In this case the frequency of c in the next generation is

$$p' = p + Bp(1-p) \qquad (3.14)$$

The rate of cha^ge in c is also a function of the initial weights, A_1 and A_2, of the models. When both models are equally important, the effect of B is greatest and c increases most rapidly. As the initial weight of either model decreases, so does the strength of the force of bias exerted on the population. For example, under horizontal transmission, when learners give larger weights to themselves than to potential models whom they encounter in deciding which trait to adopt, the rate of increase will be slowed. When one weight is zero, that is when there is only a single parent, bias has no effect at all. In more general terms, just as the change in c depends on the existence and amount of variability within the population, it is also depends on the existence and amount of variability within sets of models (Boyd and Richerson 1985:140-141).

Consider now the second model. Here we assume that the weights each cultural parent brings to the transmission process are equal, but allow for the possibility that learners learn from any number of cultural parents (m). This implies that $A_i = 1/m$, for all m models. The assumption means that we no longer have to keep track of which model in a model set is a carrier of variant c. Before there were 2^m model-set types to worry about. Now there are only m. All model sets are equivalent if they have the same number of models who carry variant c. In other words, the bias transmission rule can be simplified so that it yields the probability that a learner learns variant c, given that it encounters a model set comprised of m models, I of whom are c. This modification yields

$$\text{prob(learner c)} = \frac{I(1/m(1+B))}{I(1/m(1+B)) + (M-I)(1/m(1-B))} \tag{3.15a}$$

that in turn can be simplified to

$$\text{prob (learner c)} = I(1+B) \;/\; (m(1-B) + 2IB) \tag{3.15b}$$

Having obtained the probability that a learner learns c, given that I of m models are c, we need now to consider the probability that the model-set with I models who are c is formed. Under the assumption of random formation of model sets, this probability is

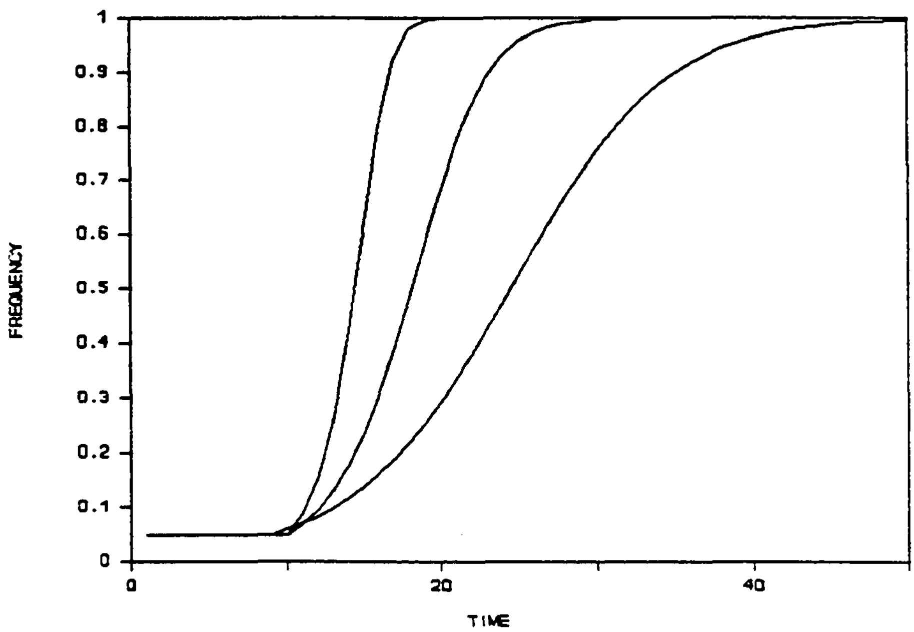


Figure 3.3. Change in the frequency of a variant favored by direct bias under transmission from two models with equal weights for B=.2., B=.4, B=.8.

given by the binomial distribution with parameter p, the frequency of c in the population. The frequency of c in the next time period is therefore

$$p' = \sum_{I=1}^{m} \frac{m!}{I!(m-I)!} p^{I}(1-p)^{m-I} \frac{I(1+B)}{(m(1-B) + 2IB)} \tag{3.16}$$

As before the frequency of c is the product of the probability that a learner using direct bias learns c from a set of models and the probability that model set is formed. The products are then summed over all m model-set types. The effects of variable numbers of cultural parents on the trajectory of change in a population using direct bias is illustrated in Figure 3.4. The rate at which a cultural variant favored by direct bias increases is a decelerating function of the number of models that enculturate learners. This result is intuitively reasonable. When the number of cultural parents is large, learners are more likely to encounter the favored variant and therefore be in a position to exercise direct bias.

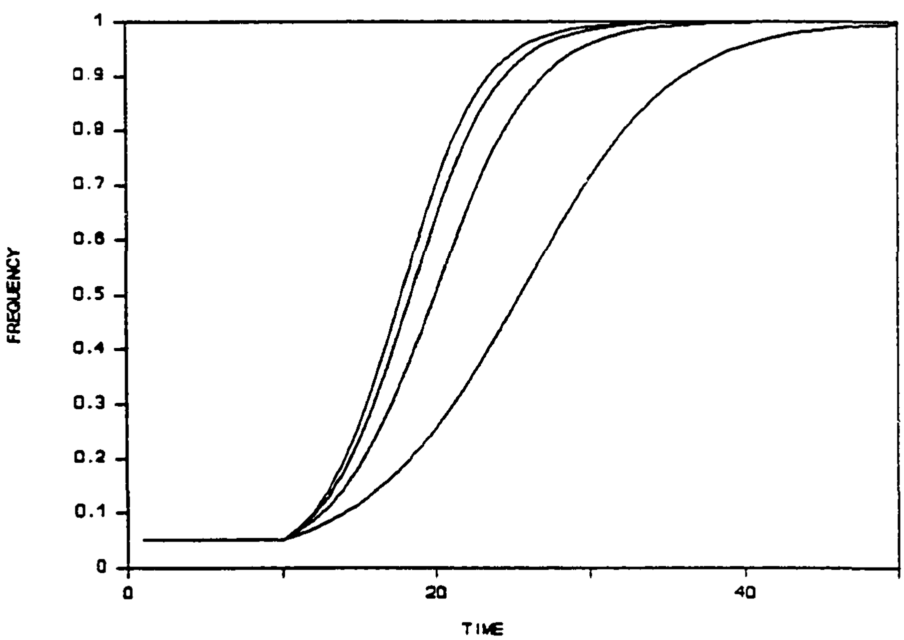


Figure 3.4. Change in the frequency of a variant under direct bias with m models of equal weight. B=.2. m=2, m=4, m=8, m=16.

3.7 Indirect Bias

The second form of biased transmission rule discussed here is indirect bias. A start at understanding indirect bias can be made by contrasting it with direct bias. As we have seen, direct bias rules allow individuals to decide whether or not to learn a particular cultural variant from a potential model on the basis of an evaluation of the variant itself. Indirect bias rules also help learners decide which of several models to learn from. A learner using an indirect bias rule first surveys the members of its model set to ascertain which models are characterized by a given value for some variable. From one of the models in the set who are characterized by that value, learners preferentially learn a second cultural trait. Following Boyd and Richerson (1985:243), I will call the variable that indicates whether or not the learner should learn from a model the "indicator variable". A cultural trait whose transmission depends on the indicator variable is termed a "secondary trait" or, in Boyd and Richerson's terminology, an "indirectly biased trait". An indirect bias rule is a prescription for learners to use a specified value of the indicator variable as a key in deciding whether or not to learn whatever variant of the secondary trait a particular model happens to possess.

There is a second noteworthy feature of indirect bias that distinguishes it from other forms of biased transmission. Direct bias rules allow learners to make choices about learning individual traits from models on a trait-by-trait basis. A given model's initial weight may be adjusted upward by a learning rule for one trait, but downward for another trait. For example, if among a population of agriculturalists, it is possible that a model's planting technique would be evaluated favorably by a learner using a direct bias or frequency-dependent bias rule, but its crop storage facilities be judged unfavorably.

Indirect bias is different in that the weight assigned to a model by an indirect bias rule affects the model's attractiveness for *many* cultural traits. In other words, any one of a number of traits possessed by a model might be favored by indirect bias on a given occasion. Learners using an indirect bias rule evaluate their models as sources of information in general rather than judge each trait taken independently.

Models of indirect bias are intended to formalize the intuitive notion that individuals might gain adaptive advantages by employing a learning rule that causes them to learn preferentially from models whom they judge to be "successful" in some sense (e.g. Flinn and Alexander 1982:394). In common-sense terms, one might think of the favored value of the indicator variable as an admired or prestigious characteristic. In an evolutionary context success means fitness. Indirect bias rules are designed by selection to increase the chances that individuals acquire secondary variants that are adaptive, that is increase fitness, in the context of the transmission system in which the rules were fixed. However, the general injunction to learn from individuals whose fitness is high is useless to learners. Learners require explicit means to identify individuals with high fitness. The adaptiveness of indirect bias depends on the stability of general characteristics that mark such individuals, individuals who are likely to possess adaptive variants. If indirect bias rules are to evolve and persist, there must be characteristics that are persistent and reliable indicators of fitness. Under such conditions, the potential advantages to learners of an indirect bias rule over a direct bias one are clear. Direct bias requires identification of the effects of a variant and their evaluation, processes that are based upon costly cognitive abilities and trial-and-error experimentation. An indirect bias rule simply requires individuals to register the value of the indicator variable (Boyd and Richerson 1985:243-244).

There are interesting parallels between indirect bias and genetically based phenomena depicted in neo-Darwinism. Sexual selection takes place in two realms, through competition among individuals for access to mates and through mate choice exercised by individuals over whom competition occurs (e.g. Smuts 1987). Indirect bias is analogous to mate choice, in which individuals, usually females, discriminate among possible mates by choosing to mate with those who are likely to contribute most to the chooser's fitness. When the contribution is genetic, as opposed to behavioral, individuals are essentially choosing mates by evaluating them as sources of genetic information. Similarly, under indirect bias, individuals evaluate models as general sources of cultural information.

Up to now, the models presented have dealt with the transmission of a single cultural trait. Building a model of indirect bias for an indicator variable and a secondary trait requires a formal framework in which individuals can be characterized simultaneously by more than one variable or cultural trait. A beginning in this direction is to generalize the zero-force model discussed previously to two cultural traits. I therefore begin by developing a simple zero-force model for two dichotomous traits. Boyd and Richardson offer an analogous treatment for two continuous traits (1985:247-252).

In order to make the algebra as simple as possible, I will limit formal treatment to the situation in which there are two cultural parents or models in each model set, both with equal initial weights, $A_1 = A_2 = .5$. Each model is characterized by a pair of dichotomous traits whose alternative values are c, d and e, f. There are four possible variant combinations that may appear in models. Let t, u, v, and w be the frequencies of each variant combination, ce, cf, de, and df, in the population during a given time period. The overall frequency of c in the population is $p=t+u$ and the overall frequency of e in the population is $r=v+w$. As before, successive time periods can be glossed under vertical and oblique transmission as generations, or under horizontal transmission as the amount of time required for learners to encounter one other model and learn from him with probability A_2 and learn from themselves with probability A_1. Given these background conditions, the model has the same two major components familiar from the single trait case. The first is a representation of the unbiased learning rule that specifies what happens when a learner encounters a model set whose two members possess particular combinations of cultural variants. With two models in each model set and two dichotomous cultural traits, there are sixteen possible model-set types. The transmission rule gives the probability that a learner acquires ce, cf, de, or df, from each model set type. The transmission rule is portrayed in the first and second columns of Table 3.2. To understand how the transmission rule works, consider the transmission probabilities for a learner confronted with a model set in which model 1 is ce and model 2 is df. The probability that the learner acquires variant c for the first trait is A_1 since c can only be acquired from the first model. Similarly, the probability that the learner acquires f as his second trait is also A_2. Hence the overall probability that the learner learns both c and f from this model set is A_1A_2. In other words, learners may learn variants of different traits from different models. The second component of the model describes the manner in which each of the model set types is formed. As before we assume that the model sets are formed at random, that is an individual's chances of becoming a model are not affected by the particular values for the two traits the individual carries. Under this assumption, the probability that a given model-set type is formed is the product of the frequencies of the variant combinations that characterize the model in the set. These probabilities are given in the third column of Table 3.2.

Combining the transmission rule and model formation scheme yields a set of four linked equations that describe the frequency of each of the four variant combinations in the following generation. Consider first the frequency of ce, given by:

$$t' = t^2(1) + tuA_1 + tvA_1 + twA_1^2 + utA_2 + uvA_1A_2 + vtA_2 + vuA_2A_1 + wtA_2^2 \quad (3.17)$$

Model-set Types		Probability Learner Acquires Variant	Probability Model-set Type is Formed
Model 1	Model 2	ce cf de df	
ce	ce	1	t^2
ce	cf	A_1 A_2	tu
ce	de	A_1 A_2	tv
ce	df	A_1A_1 A_1A_2 A_2A_1 A_2A_2	tw
		A_2 A_1	
cf	ce	1	ut
cf	cf	A_1A_2 A_1A_1 A_2A_2 A_2A_1	u^2
cf	de	A_1 A_2	uv
cf	df		uw
		A_2 A_1	
de	ce	A_2A_1 A_2A_2 A_1A_1 A_1A_2	vt
de	cf	1	vu
de	de	A_1 A_2	v^2
de	df		vw
		A_2A_2 A_2A_1 A_1A_2 A_1A_1	
df	ce	A_2 A_1	wt
df	cf	A_2 A_1	wu
df	de	1	wv
df	df		w^2

Table 3.2. Cultural transmission for two dichotomous traits with an unbiased, linear transmission rule and random formation of model sets comprised of two models.

Taking advantage of the assumption that the model weights are equal, this can be simplified considerably.

$$t' = t(t+u+v) + .5(wt+uv) \quad (3.18a)$$

Since the four variant frequencies sum to unity,

$$t' = t(1-w) + .5(wt+uv) \quad (3.18b)$$

$$t' = t - .5(wt-uv)$$

The recursions for the frequencies of the three other variant combinations are derived in the same way and lead to:

$$u'=u+.5(wt-uv) \tag{3.19}$$

$$v'=v+.5(wt-uv) \tag{3.20}$$

$$w'=w-.5(wt-uv) \tag{3.21}$$

These equations say that under unbiased transmission and random model set formation, there will be change in the frequency of the variant combinations when the second term is non-zero. The second term has the form of a correlation coefficient for dichotomous variables. Thus we can expect change when two traits are associated with one another, for example when individuals who are characterized by variant c are more likely to be e and individuals who are d are more likely to be f. On the other hand, the frequencies of the variant combinations will be stable when the two variant pairs occur independently of one another. Note the direction of change given by the signs preceding the second terms. If the two traits are initially correlated, then cultural transmission will destroy the correlation. The equilibrium is reached when the traits are no longer correlated. Thus from any set of starting frequencies, the equilibrium variant combinations are the product of the marginal starting frequencies of the variants. More formally,

$$\hat{t}=(t+u)(t+v)=pr \tag{3.22}$$

The equilibria for the other three variant combinations are analogous. While the frequencies of variant combinations change on their way to their equilibrium values, the marginal frequencies do not. In other words, transmission destroys trait correlations but leaves the overall frequency of the variants in the population unchanged. The dynamics of the system for two traits that are initially perfectly correlated are illustrated in Figure 3.5. Note that the equilibria for the variant combinations are not reached in a single time period. This phenomenon, analogous to linkage disequilibrium in population genetics (e.g. Crow 1986:20), is due to the fact that only a quarter of the model sets formed in each time period is able to teach learners all possible variant combinations. I note without a formal treatment that the approach to equilibrium is slowed when model weights are unequal. The approach is accelerated as the number of models is increased. To sum up then, unbiased transmission of multiple traits alters the distribution of variant combinations, but not overall variant frequencies.

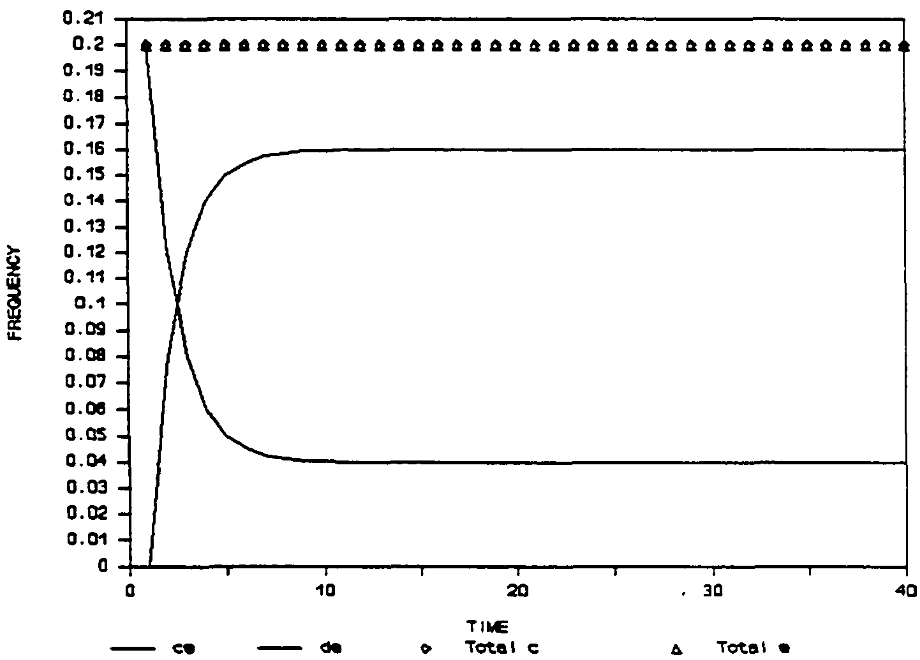


Figure 3.5. The approach to equilibrium variant combinations under unbiased transmission and random model-set formation. Initially the two cultural traits are perfectly correlated: t=.2, u=0, v=0, w=.8.

This simple multiple-trait companion to the zero-force law (3.3), makes possible a formal treatment of indirect bias. A first step toward that end is a more detailed discussion of the character of indicator variables used in indirect bias learning rules. Consider first that indicator variables may not themselves be cultural traits or, more properly, behavioral traits generated by cultural ones. Instead an individual's indicator characteristic might be the result of the interaction between culturally (or genetically) governed behaviors exhibited by him and a given set of environmental circumstances. In this case two possibilities arise. In the first, variation for a given secondary trait does not cause variation in the indicator variable. The fact that an individual acquires a particular secondary variant has no consequences for the value of the indicator variable that typifies him. This can be called simple indirect bias. The second possibility ensues from the existence of a casual relationship between the secondary trait and the indicator variable such that an individual's secondary variant does have implications for his indicator characteristic in a particular environment. In this case, although indicator traits are not themselves culturally transmitted variants, they are partially caused by interactions between behaviorally expressed cultural information and the environment. This is complex indirect bias.

Some examples may add concreteness. For simple indirect bias, consider a two-class, stratified society whose members operate with an indirect bias rule under which wealthy models have greater influence on learners than poor ones. Wealth, although it may be passed between generations, is not a transmittable cultural variant. Poor individuals do not obtain wealth by having wealthy models. On the other hand, there is wide variety of secondary traits transmitted between rich and poor. Examples might be preferences for one pottery or dress style over another. Such cultural traits do not affect the probability that the poor become rich or the rich poor. Complex indirect bias can be illustrated by an indirect bias rule used by members of a foraging population that specifies that learners preferentially choose models who are good gatherers of plant foods, who harvest the most calories per day. In this case there might will be cultural variation in harvesting techniques -- say digging stick design -- that is causally linked to harvesting efficiency. An individual using the more efficient tool design variant would have higher harvesting rate and thus be more likely to be considered a good gatherer. Note that environmental variation may alter the strength of the causal connection between an indicator characteristic and secondary traits in a single population over time. Consider a population of agriculturalists invading a new habitat who operate with a learning rule that uses land holdings as an indicator characteristic. Initially whether or not individuals employed a culturally transmitted planting technique might affect their ability to accumulate land. However, with the passage of time, the growth of population and consequent decline in land availability for individuals who do not already have it, variation in one's repertoire of planting techniques might become wholly irrelevant to the ability to acquire land. It is important therefore that models of indirect bias accommodate variation from zero to unity in the probability that individuals develop the favored indicator value, given that they culturally acquire a particular secondary variant.

We can begin with a model of simple indirect bias, in which there is no causal relationship between the indicator variable and a secondary trait. The zero-force, two-trait model developed above provides a starting point. Indirect bias leaves the model-formation component of that treatment unchanged. Hence the only modification is to the learning rule. Let trait c/d represent the non-transmittable indicator variable, with c the value favored by the indirect bias rule. Trait e/f is the culturally transmitted secondary trait. During each time period, learners have an opportunity to be instructed by two models. The indirect bias parameter B portrays the outcome of the evaluation of models by learners who use the indirect bias rule. It is the proportion by which the probability that a learner learns a model's secondary variant is raised or lowered, given that the model is or is not characterized by c, the favored value of the indicator variable. Thus the importance of one member of a model set to a learner is not only a function of his initial weight A_1, but also of his indicator variable. The required adjustment to the model's initial weight takes the general algebraic form of Equation 3.12. However, there are differences because the indicator variable is not transmitted. How the required modifications are made is best seen in Table 3.3 which portrays the indirect bias rule.

To understand the consequences of a non-transmittable indicator value, consider the probabilities that a learner ends up with each of the four variant combinations, given that his two models carry different indicator values, c and d, and different indicator values, e and f. Under the zero-force model (Table 3.2), a learner confronted with such a model set could emerge with any of the four variant combinations. In the model

Model-set Types		Numerator for Probability Learner Acquires Variant			
Model 1	Model 2	ce	cf	de	df
ce	ce	1			
ce	cf	A_1	A_2		
ce	de	1			
ce	df	$A_1(1+B)$	$A_2(1-B)$		
cf	ce	A_2	A_1		
cf	cf		1		
cf	de	$A_2(1-B)$	$A_1(1+B)$		
cf	df		1		
de	ce			1	
de	cf			$A_1(1-B)$	$A_2(1+B)$
de	de			1	
de	df			A_1	A_2
df	ce			$A_2(1+B)$	$A_1(1-B)$
df	cf				1
df	de			A_2	A_1
df	df				1

Table 3.3. Indirect bias rule, based on a non-transmittable indicator trait. Note that the probability that a leaner acquires a given variant is computed by normalizing the terms in the second panel, dividing each of them by the sum of its row.

of indirect bias, the learner can only acquire two of them, since only one dichotomous trait is transmitted. As before, the learning rule is equally applicable to horizontal and vertical-oblique schemes. In the horizontal case, model 1 is the learner who retains his/her indicator value across time periods. In the vertical case, model 1 might be a biological parent of the learner -- say a father in a patrilineal society where the indicator is wealth. Here too the learner is constrained to assume the indicator value of model 1, although he might learn either secondary variant. Limiting the treatment to two models with equal weights allows considerable simplification and yet preserves the most important dynamics of indirect bias. Union of the learning rule for two models whose weights are $A_1=A_2=.5$ with the assumption of randomly formed model sets yields a set of four linked recursions for the frequency of each variant combination in the next time period or generation. For example, the frequency of ce is:

$$t' = t^2(1)+tu.5+tv+tw.5(1+B)+ut.5+uv.5(1-B) \quad (3.23a)$$

A little algebra makes the dynamics more transparent:

$$t'=t-.5(wt-uv)+.5B(wt-uv) \quad (3.23b)$$

The equations for the remaining three variant combinations, cf, de, df are similar:

$$u'=u+.5(wt-uv)-.5B(wt-uv) \quad (3.24)$$

$$v'=v+.5(wt-uv)+.5B(wt-uv) \quad (3.25)$$

$$w'+w-.5(wt-uv)-.5B(wt-uv) \quad (3.26)$$

Note that the first two terms in these equations are identical to those in Equations 3.18 through 3.21. They represent that aspect of the transmission process that, in the absence of other forces, leads to the disassociation of indicator variables and secondary traits that are initially correlated. Interestingly this occurs at the same rate as the disassociation of pairs of traits that are both culturally transmitted. The new third term indicates that the strength of indirect bias depends upon the strength of the correlation between the indicator variable and the secondary trait. If the indirect bias parameter is zero, then the recursions and resulting dynamics are identical to those discussed above: the two secondary variants are redistributed among the two segments of the population with different indicator values, but there is no overall change in their frequency. If the bias parameter is greater than zero this is not the case. Consider the frequency of variant e among the population segment with the favored indicator value. If initially e is limited to members of the population who are c, transmission dilutes its frequency among them, while indirect bias increases it by an amount proportional to B (Equation 3.24). On the other hand, transmission increases the frequency of e among d individuals in later time periods and indirect bias adds further to this increase (Equation 3.26). As a result, there will be an absolute increase in the frequency of e in the population as a whole. The amount of increase depends on the strength of the bias and of the initial correlation. Both the bias parameter and the correlation must be greater than zero for any change in the overall frequency of e to take place. The dynamics that result are illustrated in Figure 3.6. In general, if there is initially a positive correlation between the indicator variable and the secondary trait, the equilibrium frequency of e in the population as a whole and in the population segment not characterized by the favored indicator variant will be greater than its starting value. The equilibrium frequency of e among individuals with the favored indicator value will be smaller, but not as small as it would have been under transmission alone, without the effects of indirect bias. This implies that changes in the secondary trait, whatever their cause, in the portion of the population possessing the favored indicator value will be followed by parallel shifts in the complementary population segment. The latter group will track the former.

This model is easily altered to accomodate complex indirect bias, where there is a causal connection between a secondary trait value and the favored value of the indicator trait. Once again we assume that c is the favored indicator value. In addition, we assume that an individual who learns a given value of the secondary trait, say e, has a certain probability, r, of acquiring the favored indicator value in a given time period, while individuals who learn the alternative variant, f, have the same chance of developing the indicator value not favored by indirect bias. In terms of a previous example, this means

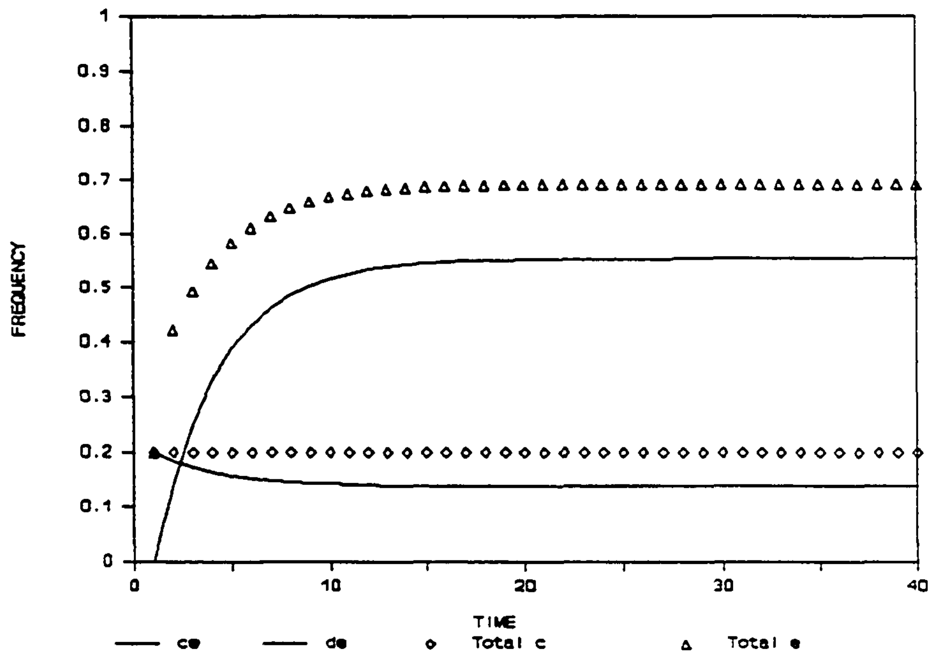


Figure 3.6. Approach to equilibrium values of secondary trait e in population segments c and d, under indirect bias for c. Initially the indicator variable and the secondary trait are perfectly correlated: t=.2, u=0, v=0, w=.8.

that individuals who use one digging stick design have probability r of becoming good gatherers during that time period, while individuals who use the alternative design have the same probability of becoming poor gatherers. The indirect bias rule operates in each time period as before. The causal interactions, which are represented by parameter r, have an opportunity to alter indicator variable frequencies in each time period after biased transmission takes place. Under these conditions, the trajectory of change is given the following equations:

$$t''=t'+rv' \tag{3.28}$$

$$u''=u'-ru' \tag{3.29}$$

$$v''=v'-rv' \tag{3.30}$$

$$w''=w'+ru' \tag{3.31}$$

where t′ through w′ are derived from Equations 3.24 through 3.27. The causal link between the secondary trait and indicator variable produces a correlation between them and maintains it in the face of the attenuating effects of transmission. Hence the secondary trait increases in frequency and it does so at a more rapid rate than the indicator value that it helps cause (Figure 3.7). If the strength of the causal link remains constant, both the secondary variant and the indicator value will increase to fixation in the population as a whole. The rate at which this happens is a function of the bias parameter and the strength of the casual connection. If either the indirect bias parameter or the probability r are zero, there will be no change in the overall frequency of either the secondary variant or indicator value in the population. When r is zero, this model is identical to the previous one. When B is zero and r is greater than zero, the secondary variants are redistributed between the two population segments until an equilibrium is reached at which there remains an imperfect correlation between the indicator variable and the secondary trait. By themselves the processes represented by r cannot drive a secondary variant to fixation or loss in either population segment because of the disassociative effects of cultural transmission.

Unlike most of the models described earlier, the indirect bias models developed above represent a substantial departure from the treatment offered by Boyd and Richerson (1985:252-254). In their model of indirect bias, the indicator variable is a culturally transmitted trait and the indicator variant, favored by the indirect bias rule, is itself favored by direct bias. This state of affairs does not match the details of many of

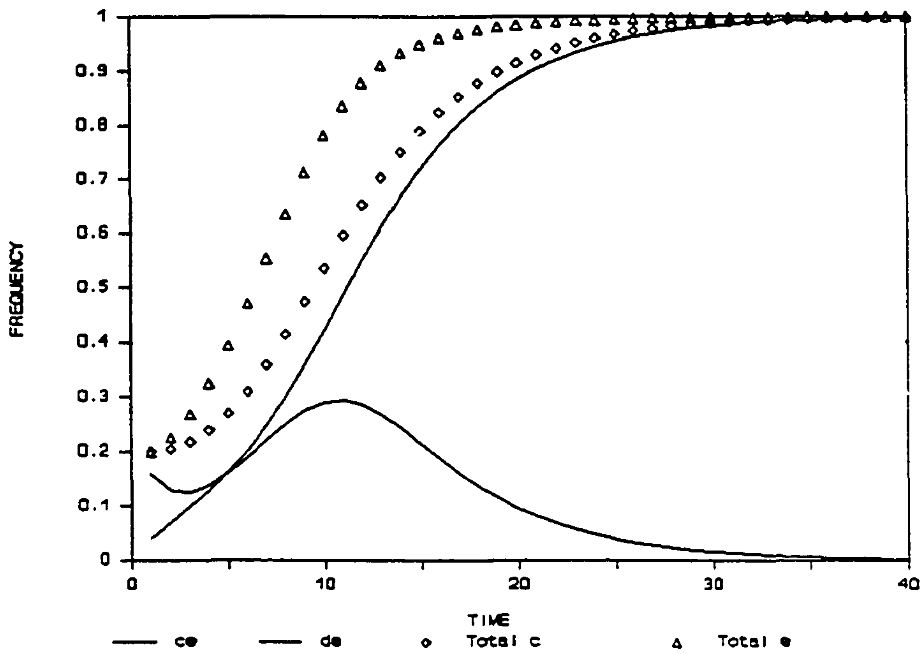


Figure 3.7. Change under indirect bias when secondary variant (e) causes the appearance of the favored indicator value (c) with probability r=.2. Starting frequencies are t=.04, u=.16, v=.16, w=.64. The indirect bias parameter B=.8.

their motivating examples that are similar to the examples I have offered above. In addition, it seems problematic from a theoretical perspective. The conditions under which deterministic evolutionary forces would favor an indirect bias rule based upon a culturally transmitted trait, as opposed to a characteristic that is a consequence of trait-environment interactions, are difficult to imagine. Whether a particular variant has adaptive consequences is wholly dependent on the environment, which is liable to be both spatially and temporally variable. It is unlikely that a culturally transmitted trait would be a reliable indicator of model fitness over a sufficient span of time for an indirect bias rule based upon it to be fixed.

3.8 Selection

As I emphasized in the previous chapter, natural selection acting on genetic variation is in theory ultimately responsible for the existence of a cultural transmission system with a given set of structural rules. In addition, there are good theoretical reasons to believe that neo-Darwinian selection will equip individuals with learning rules which introduce directional forces discussed in the previous sections, guided variation and bias. However, as we saw in the previous chapter, genetically based individual learning and learning bias may be weak enough to allow the existence of heritable -- more broadly, transmittable -- cultural variation in a population of social learners. When this is the case, the stage is set for the operation of emergent forces, selection and drift, on cultural variants. In the following two sections I offer simple models of these two forces.

First I tackle selection. Darwin offered natural selection as the principle mechanism responsible for descent with modification and the consequent diversity of the organic world. As axiomatized by Lewontin (1974b), the deductive theory had three simple components, each of them an observation about the world:

1. Individuals vary.
2. Variation is heritable, so variant individuals leave offsping that resemble them.
3. Different variant individuals have a characteristic tendency, caused by interaction with their social and natural environments, to leave different numbers of offspring.

From these observations, evolution -- in this case, change in the frequency of genetic variants in a population -- follows mechanically. Various authors have noted that the same consequences will arise if the variants are cultural and not genetic instructions (e.g. Campbell 1965, Dunnell 1980, Durham 1982, Cavalli-Sforza and Feldman 1981:101-103, Boyd and Richerson 1985:173-174). Minor alterations to the wording of the second and third propositions cited above render the relevance to cultural evolution explicit:

2′. Variation is transmittable, so that individuals who learn from variant models resemble their models.

3′. Different variant individuals have a characteristic tendency, caused by interaction with their natural and social environments, to become models for different numbers of learners.

Here again, cultural evolution -- change in the frequency of cultural forms in a population of social learners -- will occur as a mechanical consequence.

It is important to be clear on the distinction between bias and selection. When individuals learn using bias rules, they decide from which model among those encountered in a model set they will learn. Learners select models on the basis of an algorithm with which they have previously been equipped by selection. This means that explanations for the outcome of the exercise of bias rules are incomplete without an hypothesis concerning the origin of the algorithm. For the most part, selection is different. The operation of selection in a population of social learners does not require choices to be made by learners. Selection affects the probability they will encounter models carrying certain variants in the first place. Selection is an autonomous process not requiring individuals to exercise decision capacities acquired previously in their evolutionary history (Boyd and Richerson 1985:174-175). Note the qualifying phrase "for the most part." As I noted in the previous section, indirect bias is similar in many ways to sexual selection via mate choice in neo-Darwinian theory. Like model choice, mate choice requires that individuals be equipped with a decision algorithm. Recognition of this fact is one motivation for the traditional evolutionary distinction, originating with

Darwin, between natural and sexual selection. The important issue is not what to call these phenomena, but to grasp the reason for the distinction.

Two further points, touched on in Chapter 2 regarding selection and its relationship to learning rules, are worth reviewing. Recall that systems of genetic and cultural transmission may have different structures. When this is the case, variants that increase an individual's chances having genetic offspring, may not be coextensive with variants that increase the chances of becoming a model for social learning. In other words, when non-parental, especially horizontal, transmission is an important means by which individuals acquire cultural information, selection on cultural information will favor variants that may decrease an individual's fitness relative to optima assessed in neo-Darwinian terms. On the other hand, when cultural transmission is vertical, selection will favor the same variants, whether they are based on genetic or cultural innovation. As we have seen, the mathematical forms of models for the cultural transmission of a single discrete trait and for haploid genetic transmission are identical. ESS models for the outcome of frequency-dependent selection are therefore more faithful representations of vertical cultural transmission than transmission in the diploid genetic systems for which they were developed and to which they are routinely applied (cf. Rogers 1988).

The second point concerns the kinds of cultural variants subject to selection. When there is transmittable cultural variation, the cultural variants that are sorted by natural selection, or possibly by drift, might themselves be variant learning rules responsible for guided variation and the various forms of bias. In other words, given the existence of variation in learned strategies and criteria for evaluating both internally generated and socially learned variants in a population, such culturally based learning rules will themselves be subject to selection. Selection would favor cultural learning rules that cause individuals to learn variants that in turn enhance their probabilities of becoming models.

Taken together these two observation imply a third. When the inheritance structure in which learning rules are transmitted is asymmetric to genetic transmission, rules that are favored by selection may depart systematically from genetically constrained ones. This means that we cannot necessarily expect that all rules for individual learning and biased transmission will favor neo-Darwinian optima. It depends in part upon the structure of the transmission system in which they were fixed.

A simple model of the natural selection of cultural variants can be constructed as follows (Cavalli-Sforza and Feldman 1981:101-107, Boyd and Richerson 1985:180-182). As in our previous treatment there are two variants, c and d, for a single trait. As noted above, selection does not operate through learning rules. Hence the component of the zero-force law that describes learning rules remains unaltered. The model set formation component requires revision. In our previous treatments, we have assumed that models were drawn from the population at random. In other words, an individual's cultural variant had no effect on the number of times the individual became a member of a model set during each time period. In order to model selection, this assumption is relaxed.

It is customary in discussions of natural selection of genetic variants to distinguish between viability and fertility components of selection (e.g. Roughgarden 1979:26-28, Vrba and Eldredge 1984 :155-156). A similar distinction can be made in the cultural case. For analytical convenience, we will assume that during each time period, individuals are sequentially exposed to risks of differential viability and then differential fertility. Viability selection of cultural variants occurs when variant individuals differ in the probability they will continue as members of a social learning population long enough to become members of a model set. Viability selection therefore operates through the differential removal of variant individuals from a population of social learners. Under vertical transmission, this occurs through the actual deaths of individuals prior to attaining reproductive age. Differential mortality may also cause selection under horizontal transmission when individuals die before having a chance to pass on maladaptive information. Viability selection may also be driven by selective out-migration of individuals with certain variants from a population before they have a chance to become models.

Fertility selection covers those processes that cause variant individuals, given that they remain in the population until model sets are formed, to serve as models for different numbers of learners (l) in each time period. Potential causes of fertility differentials are analogous to those discussed above. When traits are vertically transmitted the number of learners is the number genetic of offspring. Under horizontal transmission, differences in the number of learners taught by variant models may arise in more complex ways that depend upon current arrangements by which individuals acquire particular sets of cultural variants. Just how such a process might work is discussed in Chapter 5.

For now only the combined effect of the fertility and viability components of selection is of interest. Ignoring complications introduced by differences in the shapes of offspring distributions, it can be represented in a single parameter, $W=lm$, that is the average number of times an individual with a given variant becomes a model during each time period or, equivalently, the average number of learners a variant individual teaches. Thus W combines viability and fertility into a single measure of an individual's fitness or expected contribution to the population's cultural repertoire in the next time period, that is the average number learners taught by an individual with a given variant.

To model selection, we assume that the value of W is different for each of the two variants. If W_c and W_d are the fitness of variants c and d respectively, then the relative frequency of c in the next time period is given by:

$$p' = \frac{pW_c}{(1-p)W_d + pW_c} \tag{3.32}$$

The denominator of this equation is the mean fitness, W, of the population. It is the average number of learners produced by each individual in each time period. Thus 1 - W = r is the growth rate of the population. Similarly, $1-W_c$ is the rate at which individuals who have learned c are added to the population. In population genetics, the W's are called absolute fitnesses. As we shall see later in our discussion of selection for two traits, it is often helpful to covert the W's to relative fitnesses by dividing them by the W associated with the fittest variant. Assuming that c is the fittest variant, the relative fitnesses are given by:

$$w_c = W_c/W_c = 1 \qquad (3.33)$$

$$w_d = W_d/W_c = 1\text{-}s$$

Here s is a selection coefficient, the difference between the relative fitness and 1. It measures the strength of selection against a variant, while relative fitness measures the strength of selection for it. The speed with which selection proceed

Using these equalities, 3.32 can be rewritten as follows:

$$p' = \frac{p}{p + w(1\text{-}p)} \qquad (3.34)$$

The trajectory of change under selection is illustrated in Figure 3.8. Note that, as with direct bias, the speed with which the favored variant increases is a function of the variance of the trait in the population.

3.9 Cultural Drift

Cultural drift, like selection, sorts cultural variants without the mediation of learning rules. However, unlike selection the sorting process is stochastic, that is the specific outcome of the process is not determined once the initial conditions are specified. In population genetics, drift refers to the changes in allele frequencies that necessarily occurs as a result of sampling error in the process of reproduction. An exactly analogous process occurs in cultural transmission when populations of social learners are limited in size and the strength of selection and biased transmission favoring one variant over another are small to non-existent. When populations are finite, individuals with certain variants happen by chance to serve as models for more learners than individuals with other variants. Thus cultural drift sorts variants, but in each time period all variants have more-or-less the same chance for increasing or decreasing in frequency. The

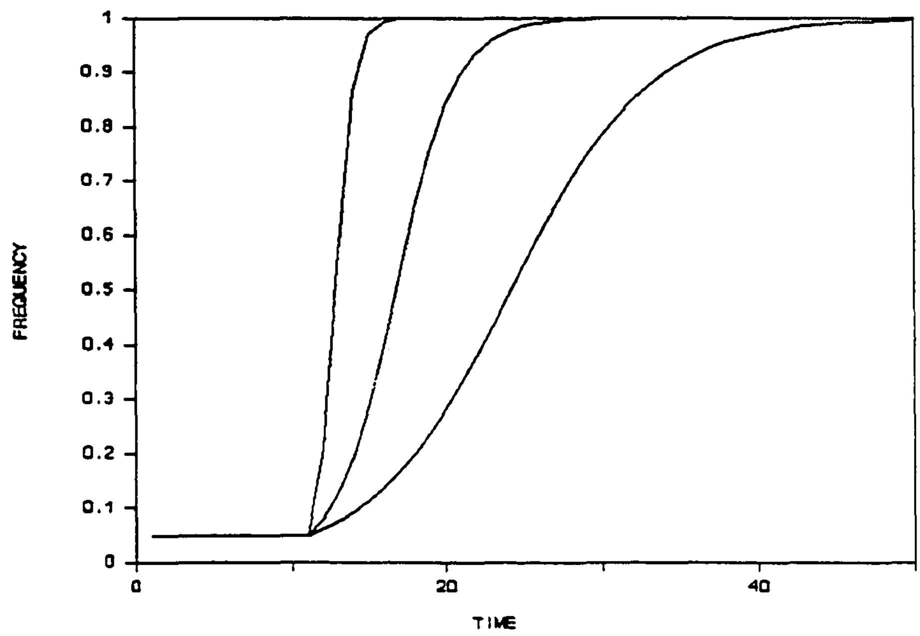


Figure 3.8 The effects of selection for a cultural variant (c) on its frequency in a population. Relative fitness of the favored variant is $w_c = 1$. For the alternative variant, the relative fitnesses are $w_d = .8, .4, .2$.

qualification is important. When population sizes are small, sampling error can defeat modest differences in expectations for frequencies of alternative variants arising from deterministic models.

Population geneticists have expended a great deal of effort modelling genetic drift with an eye to developing analytical results concerning such matters as fixation and loss probabilities for neutral alleles and probability distributions for allele frequencies as a function of time and population size. The models are among the most mathematically sophisticated in the field (e.g. Crow and Kimura 1970:371-382). Many of them can be applied to cultural transmission with minor alterations (e.g. Cavalli-Sforza and Feldman 1981:112-121). Here I review a few of the simpler analytical results and supplement them with the output from a simple computer simulation. A simulation-based approach yields some simple generalizations about the expected shape of variant trajectories in time under drift which are not available from an analytical approach.

The simplest analytical model of drift portrays it as a form of binomial sampling. Consider first vertical and oblique transmission in a population of size n with two cultural variants, with frequencies p and $q=(1-p)$. Time periods are here biological generations. Offspring learn from members of the previous generation chosen at random. The expected frequency of the first variant in the next generation is $p'=p$. No change is expected at all. However, because the population is finite and who learns from whom a random process, the actual frequency will depart from expectation. Some models by chance happen to teach more learners than others. As a result, the variants they carry increase in frequency. The departure from expectation is a function of the variance, $\sigma^2 = pq/n$, of a binomial variable about its mean, p. In other words, p' is a random variable with mean p and variance σ. The amount of change to be expected between successive time periods is a function of σ and therefore of $\sqrt{}n$. In technical terms this means that drift is a special kind of stochastic process, a random walk or Markov process in which variant frequency at each time period is dependent on the immediately preceding time period. With the help of a little matrix algebra, this approach can be extended to provide expectations concerning the probability that the population will be characterized by any given variant frequency t time periods in the future (e.g. Roughgarden 1979:65-76, Cavalli-SForza and Feldman 1981:111). I will not pursue this approach here.

Horizontal transmission can be handled in this framework in several ways. The simplest is the one I shall use. It turns on the stipulation that each time period represents the amount of time required for an individual to learn from another with probability $1-A_1$, where A_1, the probability that an individual retains his old variant, equals $1/n$. Under these circumstances, the horizontal treatment is identical to the vertical one.

We can begin to build a simple computer model of the temporal dynamics of cultural drift. First consider a population of (N) individuals. At the outset each is characterized by one of a set of mutually exclusive alternative cultural variants. During successive time periods, each individual has an opportunity to learn by contacting another population member, a potential teacher or model, chosen at random. Individuals learn the variants carried by their chosen models with a preset probability (P). Setting this probability less than unity allows for the possibility that individuals are conservative, that is are disinclined to learn from others. This means that a time period is roughly equivalent to the amount of time it takes for an individual to learn from population members (including itself) with probability P. Although, this formulation emphasizes horizontal cultural transmission, the time periods of the model can also be thought of as biological generations under vertical or oblique cultural transmission schemes. A final feature allows for innovation at a specified rate equal to the probability that an individual introduces a novel variant to the population during a single time period. The innovation rate represents random variation. Both the simulation and the models to follow are based on the assumption that the number of possible variants for a single trait

Figure 3.9 Loss of variation under drift when the innovation rate equal 0 is a function of population size. Top: N=25 individuals. Bottom: N=100 individuals.

is large enough that novel variants do not duplicate ones that were ever present in the population previously. Note that this assumption may not be a reasonable construction of human innovation since cognitive constraints may increase the chances of repeated independent introduction of the same variant in a single population.

What do the dynamics of change under drift look like? To begin with, if the innovation rate is zero, drift rapidly leads to the depletion of variation in the population. Typical results for population sizes of 25 and 100 individuals are illustrated in Figure 3.9. This and similar figures to follow are to be read as (left-justified) seriation diagrams. The vertical axis represents time, while the length of the bars along the horizontal axis represents the frequency of a variant in the population. In the simulation starting frequencies for 10 mutually exclusive variants are drawn at random from a uniform distribution. As expected, a single form tends to fixation, driven solely by sampling error in the learning process. As these examples show, this happens faster in small populations than in large ones. In other words, the rate of loss of variation is an inverse function of population size. This result has long been appreciated in population genetics where it has been characterized algebraically with varying degrees of complexity (e.g. Roughgarden 1979:65-67). One of the simpler models (Crow 1986:43, Crow and Kimura 1970:101) can be adapted to cultural transmission by thinking of the process in terms of the increase in homogeneity of the population in successive time periods. Here homogeneity (F_t) has a technical meaning: the probability that the cultural variants of two randomly chosen individuals are copies of a common antecedent variant. We begin by asking the following question. If we draw one individual from the population, what is the probability of drawing a second individual who learned his variant from the same model as the first. Under random learning the answer is 1/n. The probability of getting a second individual who did not learn his variant from the same model as the first is 1-1/n. If the second individual did not learn from the same model, there is still a chance that his model learned from the same model as the first's model in the previous generation. This probability is F_{t-1}. Combining probabilities leads to a recursion for the value of F in successive time periods:

$$F_t = 1/n + (1-1/n)F_{t-1} \tag{3.35}$$

Thus under drift, the increase in homogeneity in successive time periods is proportional to 1-1/n. Looked at the other way around, the decrease in heterogeneity, the probability that two individuals do not share the same variant, is proportional to 1/n. Homogeneity in turn can be converted into an estimate of the number of variants extant in the population. The estimate, which can be called the effective number of variants after its population-genetic analogue, turns on the assumption that all variants are at equal frequencies. It is simply the reciprocal of F (Crow and Kimura 1970:323-324).

What happens when innovation is possible? To explore this question, we start off our imaginary population with a single variant but allow the introduction of novel variants at a given rate during each time period. Typical results for 100 time periods are shown in Figure 3.10. The simulation portrays the result of combining two forces: drift and random variation. Since our simulations begin with a single variant, several time periods are required for the system to reach an equilibrium at which the number of variants entering the population through random variation equals the number lost through drift.

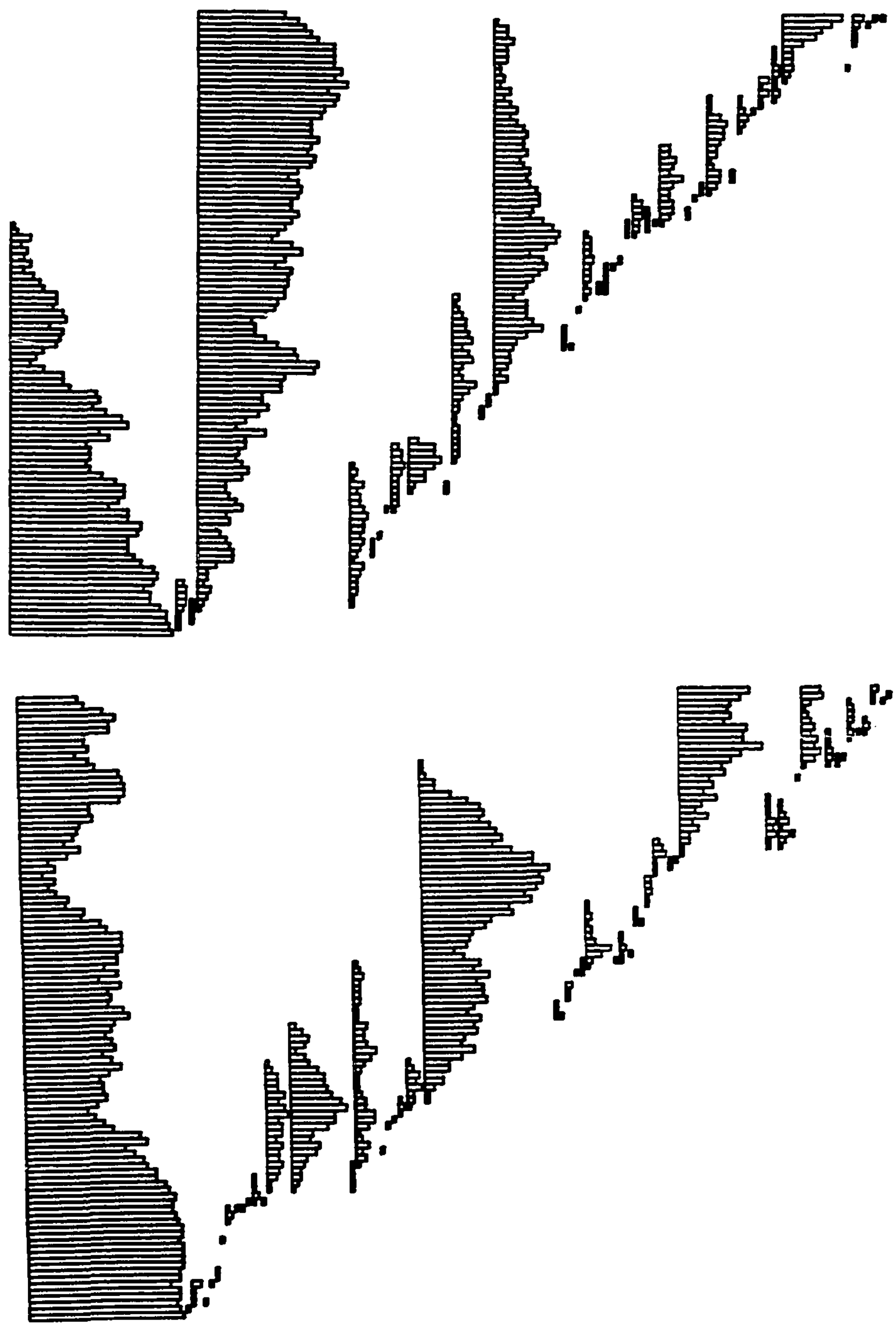


Figure 3.10 Two examples of the trajectory of change under drift with innovation: N=50, innovation rate=.01, 100 time periods.

This equilibrium can be characterized in a simple way by adding random variation or innovation to 3.35 (Crow 1986:46, Crow and Kimura 1970:323). Equation 3.35 gives the probability that two variants are copies of a common ancestral variant. If innovation is possible, the probability that those same two variants will continue to share a common ancestor is simply the probability that neither of them has been replaced by a novel variant. If μ represents the innovation rate per trait per time period, that probability is $(1-\mu)^2$. Hence

$$F_t = [1/n + (1-1/n)\, F_{t-1}\,]\,(1-\mu)^2 \qquad (3.36)$$

The equilibrium, reached when F_t equal F_{t-1}, is

$$\hat{F} = (1-\mu)^2 \,/\, N - (N-1)(1-\mu)^2 \qquad (3.37)$$

which, assuming μ is very small and terms of order 2μ can be ignored, can be simplified to

$$\hat{F} \approx 1 \,/\, (2n\mu + 1) \qquad (3.38)$$

This means that under drift homogeneity of a population is a decreasing and decelerating function of either the innovation rate or the population size. Conversely, as population size or innovation rate increase, so does the effective number of variants.

Casual inspection of the Figure 3.10 suggests several generalizations concerning the morphology of variant trajectories that may prove useful in identifying drift in the real world. Most variants never catch on, but a few do. Longer-lived variants tend to reach higher maximum frequency. In addition, two characteristics of trajectory shape appear to lurk beneath short-term fluctuations in variant frequencies. First, trajectories tend to be lenticular: low popularity early and again late in a variant's existence. The point of maximum popularity tends to be located at the middle of a variant's existence.

Below I try to describe these patterns in a more precise manner by measuring variant durations, frequency, and shape. The following results were derived by combining multiple simulation runs, each 200 time periods long, for a population of 50 individuals and an innovation rate of .01 novel variants per individual per time period.

Most variants never really get off the ground, but a few enjoy phenomenal success. The disparity can be appreciated better with the help of a simple measure of the success of a variant, its size, the sum of its (absolute) frequencies over all time periods. I computed sizes for all variants. Over a third of the variants (38%) introduced into the population persist only a single time period. These variants were never adopted by an individual other than their originator. Thus a high proportion of the variants that ever exist in a population are idiosyncratic. Because they are not transmitted, they are not cultural in the strict sense. In addition, many variants were adopted by only a handful of individuals. For example, 30 % of the variants were transmitted three or fewer times. While variants with short durations and few learners are numerically dominant, they would be difficult to detect for an outside observer sampling individuals from the population. During any given time period, individuals with idiosyncratic variants comprise only 2% of the population, while individuals with

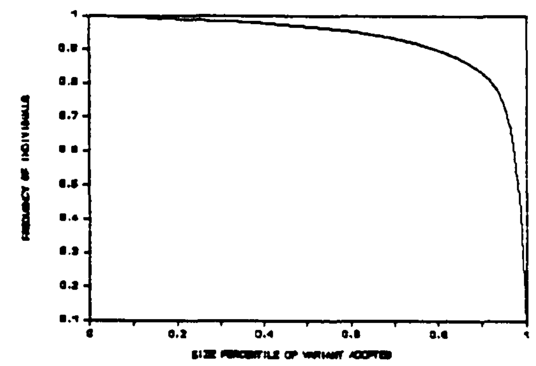


Figure 3.11 Cumulative proportion of individuals adopting variants by percentiles of variant size. Only variants originating and terminating during the simulation are represented.

variants that will eventually be transmitted three or fewer times comprise only 4% of the population. These results are summarized in Figure 3.11. It portrays the proportion of individuals in a randomly chosen time period adopting variants that eventually reached a given size. Size is represented by its percentiles. Thus, for example, at any given period roughly 80% of the population adopted variants that were sufficiently successful to rank in the top 8% of all variants in terms of size.

There is a simple relationship between the frequency eventually attained by longer-lived variants and their duration. Under logarithmic transformation, maximum frequency is a linear function of duration. The slope of a line, fit by least squares is 1, implying that maximum frequency is proportional to duration. This makes sense since, at a given variant frequency and population size, the expected amount of change in variant frequency from one time period to the next is the same for all variants.

Given our interest in temporal patterning, it would be helpful to have some way of characterizing the expected shape of the trajectory of a variant that happens to be successful. In their study of random branching and extinction of species within clades, Gould et al. (1977:26-27) developed several statistics to measure shapes of temporal trajectories. Two of them, Center of Gravity (CG) and Uniformity (UNI) are well suited for our purposes. CG, as the name implies, measures the relative temporal position of a variant's mean frequency. It is computed by measuring the position of the variant's mean frequency over the duration of its existence and then scaling that duration between 0 (time of inception) and 1 (time of disappearance).

$$CG = \Sigma_{t=1}^{d} f_t t/d \qquad (3.39)$$

where f is the frequency of the variant in a given time period and t indexes the time periods of a variant's existence from 1 (inception) to d (disappearance). Variants whose greatest frequency occurred early in their existence have CG's less than .5, while those that flourished late in their duration have CG's greater than .5. Symmetrical trajectories, with their maximum popularities at their midpoints, have CG's of about .5. UNI is a measure of the extent of fluctuation in frequency of a variant over its duration. It is the proportion of the area of a rectangle, whose width is the variant's maximum frequency and length is its duration, occupied by the variant's actual trajectory.

$$\mathrm{UNI} = \Sigma_{t=1}^{d} f_t \,/\, d \max(f) \qquad (3.40)$$

Trajectories shaped like rectangles have UNI's close to 1, while those with a very few periods of high frequency, surrounded by periods of low frequency have UNI's near 0. Trajectories with maximum frequency at midpoints from which they tend to decrease gradually forward and backward in time have UNI's of about .5.

Values of CG are presented in Figure 3.12 as a function of duration. Variants that are short lived tend to have CG's greater than .5. As duration increases, CG's decrease. The reason for this is not hard to fathom. Trajectories are constrained to begin with starting frequencies of 1. However, just before their disappearance they may have frequencies greater than one. In other words, because novel variants are counted before they are transmitted, the simulation trajectories are likely to have pointed bottoms and slightly truncated tops. This effect is attenuated with longer variant durations. The curved scatter of CG values in Figure 3.12 suggests that as duration passes 30 time periods, CG approaches .5. In fact, the mean value of CG for variants with durations greater than 30 is .515 (s=.075). The important implication for expected

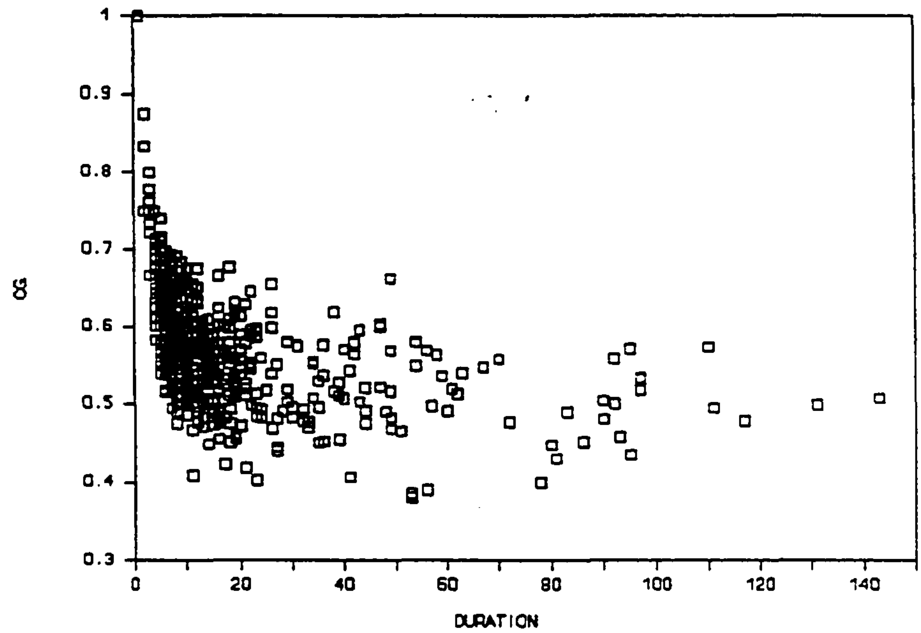


Figure 3.12. Values of CG for variant trajectories as a function of duration, generated during 20 simulation runs: N=50, innovation rate=.01, 200 time periods. Only variants originating and terminating during simulations are included.

trajectory shape is that trajectories tend to have their maximum frequencies at their midpoints.

As Figure 3.13 indicates, there is a similar attenuation in the value of UNI. High values of UNI are more likely for short-lived variants because short duration offers little chance for variation in frequency. Consider the extreme case: a variant learned by a single individual for a single time period has a UNI of 1. However, notice that at higher durations, UNI surprisingly descends below .5. The mean value of UNI for variants whose durations exceed 30 time periods is .429 (s=.050). Gould et al. noted a similar

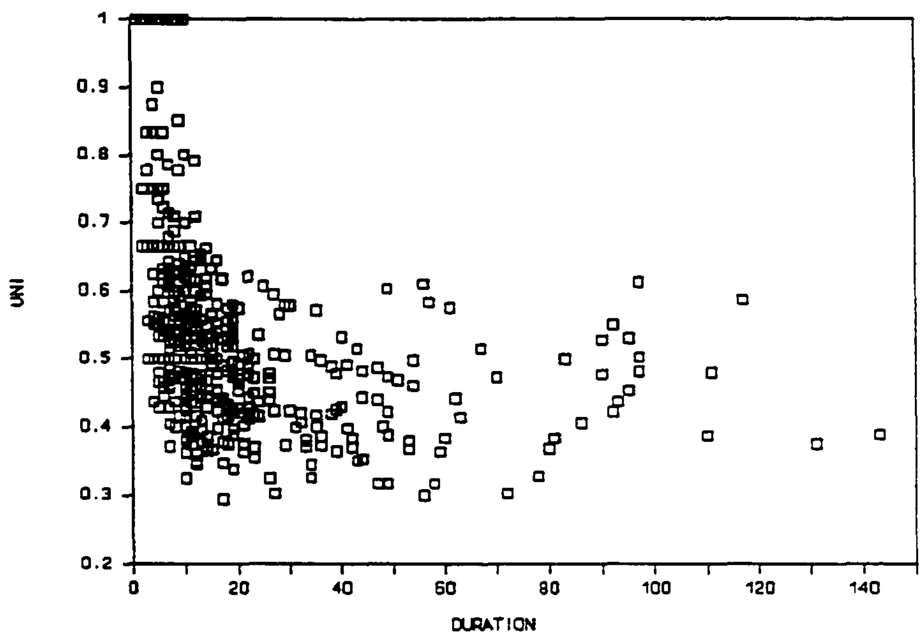


Figure 3.13 Values of UNI for variant trajectories as a function of duration, generated during 20 simulation runs of 200 time periods; N=50, U=.01. Only variants originating and terminating during simulations are included.

phenomenon in their study of clade diversity (1977:29). It thus appears to be not an artifact of the simulation but a real property shared by two quite different stochastic processes. UNI's less than .5 suggest that trajectories under drift tend to depart from a straight-sided symmetrical diamond whose UNI equals .5. The departure arises from the fact that variant frequencies are not monotonic, but tend to wander back and forth on their way from their originations to their maxima and from their maxima to their terminations.

That a stochastic process like drift should generate orderly and predictable results of this sort is initially counterintuitive. The apparent order arises from two sources. First, the trajectories of variants by definition begin and end with zero frequency. In technical terms, zero frequency is an absorbing barrier. However, with random variation, fixation is not. The second arises from the Markovian character of the process under which changes in successive periods are incremental and the frequency of a variant depends on what happened in the previous period. Under these conditions, sudden changes in variant frequency are unlikely and lenticular trajectories are to be expected.

This chapter has offered a review of some simple consequence laws that describe the forces responsible for cultural evolution. These forces can be divided into two broad categories that lead, on the one hand, to the introduction of cultural variation into social-learning populations and, on the other, to the sorting of that information. Variation is introduced into populations by five processes: random variation, guided variation or individual learning, migration, indirect transmission, and simple indirect bias Three forces sort cultural variants in a deterministic fashion: direct bias, complex indirect bias, and selection. Individual learning, direct bias, and indirect bias are derived forces in the sense that they depend on the prior existence of learning rules that themselves must be regarded as the result the prior selection of genetic or cultural variants. If transmittable cultural variation exists in a population then there is scope for the operation of selection, the third means by which cultural variants are sorted deterministically. Finally, a fourth force, drift, sorts variants in a stochastic fashion, producing remarkably orderly results.

Chapter 4

Implications of Consequence Laws for Archaeological Inference

4 Introduction

In this chapter I draw together the implications for archaeological inference for the models of cultural evolutionary processes presented in the previous chapter. First I examine the implications of the models for the shape of cultural variant trajectories in populations of social learners. The motivation is a simple one: to explicate how empirically documented patterns might be useful in testing hypotheses about the processes that produced them. Next I outline, in a framework compatible with the evolutionary approach, the manner in which cultural processes are mapped onto the archaeological record. This a necessary step if consequence laws are to have useful consequences for archaeologists. I offer a detailed treatment of this problem for cultural drift. The same sort of argument can be applied to the other forces. I return for the last time to the argument we last left in Chapter 2 concerning the functional morphological approach to behavioral inference. The simple models of the previous chapter allow an informal portrayal of how inferences based on functional morphology are really hypotheses about evolutionary processes. Finally, I consider how the organization of complex social systems can be expected to affect the operation of several evolutionary forces, indirect bias, drift, and indirect transmission. Thus this chapter brings to an end the long theoretical argument begun in Chapter 1 and paves the way for the empirical application of some of the ideas outlined along the way.

4.1 Temporal Patterning of Cultural Variant Frequencies

Among the benefits of explicit consequence laws are explicit expectations concerning temporal patterning in variant frequencies caused by different evolutionary forces. Comparisons between these expectations and empirical patterning can offer clues concerning the kinds of processes responsible for variation in particular historical cases, as long as the patterns are rendered in theoretically appropriate terms. Recall Lewontin's admonition, noted in Chapter 1, that we cannot go out and describe the world in any way we please and then sit back and demand an explanation. Consequence laws deliver not only expectations concerning empirical patterning, but also the means to describe it in meaningful ways.

4.1.1 Style and Function

Fundamental to pattern description is a distinction between two classes of difference among alternative cultural instructions: style and function (Dunnell 1978). As a first approximation, the difference between two cultural variants is functional if they result in fitness differences among individuals who incorporate them into their behavioral phenotypes. To specify the function of a variant is to give an account of the effects, caused by interactions between the properties of the behaviors generated by that variant and the environment, which engender fitness differences. Behavioral implementation of functional variants will have significant matter-energy cost entailments whose outcome is summarized in the expected reproductive success of individuals characterized by variants. Hence fitness means expected reproductive success, as in neo-Darwinian theory. However, because we are dealing with cultural transmission, we must acknowledge the possibility that reproduction includes not only the production of biological offspring, when variants are vertically transmitted, but also the production of learners who are not biological kin, under asymmetric transmission structures, especially horizontal transmission. This means that when we frame hypotheses about fitness, we need to specify the transmission structures in which fitness differences are realized. In the terminology developed in the previous chapter, a cultural variant is functional if, relative to an alternative variant, it alters the probability that its bearer will become a member of a model set. Function affects the model-set formation component of the transmission process.

The difference between two variants is stylistic, on the other hand, if they do not give rise to fitness differences among individuals who incorporate one or the other of them into their phenotypes. In other words, a variant is stylistic if, relative to some alternative, it is selectively neutral. Note that this is not to say that stylistic variants are cost free. The behavioral implementation of any cultural instruction has a cost. Hence the amount of time and energy invested in stylistic behavior in general is potentially a matter of selective importance (Meltzer 1981:314). The relevant selective neutrality resides in the fact that one behavioral alternative is not inherently superior to another in selective terms at a given level of investment in style. Note that the style-function dichotomy is a useful, if artificial, discrete measurement of what, in fact, is a continuous scale. After all, fitness is a continuous variable. This implies that, given small enough population sizes and/or small enough fitness differences between variants, drift variants will be sorted by drift. Divergence caused by such sorting may be considered stylistic.

The consequence laws of the previous chapter not only offer the theoretical basis for the style-function dichotomy, but also generalizations concerning patterning that can be helpful in identifying stylistic and functional variation in empirical phenomena. Once stylistic and functional variants have been identified, we can then use consequence laws to diagnose which forces are responsible for altering or preserving variant frequencies. The successive moves from consequence laws to style and function and back again comprise an inferential strategy that is the subject of the following two sections. Herein lies the practical utility of consequence laws.

4.1.2 Distinguishing Stylistic and Functional Variation.

How is the style-function distinction to be made and tested in empirical applications? One initially promising approach lies in the possibility that stylistic and functional variants themselves might display distinctive sorts of temporal patterns. This approach figured importantly in the motivation behind Dunnell's original formulation of the style-function dichotomy (1978:199-200). Dunnell pointed out that trajectories of functional elements were controlled by selection and external contingencies, while stylistic elements would "display a very different kind of behavior." Citing Gould et al.(1977), he suggested "a profitable direction may lie in identifying stylistic elements by their random behavior"(1978:199). The drift simulation and the deterministic models of Chapter 3 allow a more detailed discussion of the possible differences between temporal patterning of stylistic and functional variants.

Drift, by definition, sorts stylistic variants in a stochastic fashion. Given a source of transmittable variation, the result is the Markovian, lenticular curves described in the previous chapter. Within a single social-learning population, change in stylistic variants, necessarily proceeds at more-or-less constant rate set by the innovation rate and population size. The pace of stylistic change is not directly controlled by environmental parameters.

By contrast, the tempo of change in functional variants sorted by selection is necessarily tied to the change in adaptively important features of the environment. Two scenarios may be distinguished on the basis of rates of change in environmental parameter values. Both assume the existence of transmittable variation in the population. The first posits relatively long periods of environmental stability between relatively rapid shifts. Spacing between shifts is sufficiently long to allow selection to push fitness-enhancing variants to fixation. In this case, functional change might be distinguishable from stylistic change by the existence of punctuated transitions from low to high frequencies for fitness-enhancing variants whose timing is correlated with environmental shifts.

The second posits a constantly changing environment, in the form of either frequent rapid shifts or temporal clines in environmental parameter values. If variant-environment interactions are such that the environmental values yielding fitness optima for each of a suite of variants occur at intervals, we might expect successive replacement of variants as values cross the fitness optima of successive variants. Populations, pulled by selection, are in effect forever chasing a moving adaptive peak. In a neo-Darwinian context, this kind of situation has been described in the Red Queen hypothesis (Van Valen 1973). The rate of resulting successive replacement of functional forms is governed by the speed of environmental change. Judged solely in terms of the pattern of successive replacement exhibited by variant trajectories, this case might be very difficult to distinguish from drift-driven stylistic turnover.

Dunnell's (1978) original expectations concerning stylistic and functional patterns produced by drift and selection might be fleshed out as follows. Punctuated transitions correlated with adaptively salient environmental shifts would mark functional variants. On the other hand, gradual turnover independent of environmental dynamics would be characteristic of style. The dependence of variant frequencies on environmental parameter values might help distinguish successive replacement of functional forms under a Red-Queen regime from stylistic turnover driven by drift.

As the models in the previous chapter should make plain, selection and drift are not the only forces that alter the frequency of cultural forms in populations of social learners. Hence any attempt to attribute distinctive temporal patterns to stylistic and functional variants needs to take into account the manner in which their patterning is affected by these other forces. How then do additional evolutionary forces affect the trajectories of stylistic and functional variants?

Individual learning and direct bias should mimic the temporal patterning of selection. Since selection is resposnible for the fixation of the rules, most of the cultural variants affected by these deterministic processes should be functional. Guided variation will tend to cause the repeated introduction of functional forms into the behavioral repertoires of individuals. Direct bias will tend to sort functional variants already present in the population. The same expectation holds for complex indirect bias, when secondary variants cause individuals acquiring them to develop favored indicator characteristics. Recall that indirect bias sorts any trait that is correlated with an indicator variable. When phenotypic expression of a secondary variant increases the probability that an individual will acquire the positively weighted indicator characteristic (Equations 3.28-3.31), the resulting dynamics will resemble selection. The secondary variant favored by indirect bias will be selectively advantageous, to the extent that the favored indicator characteristic that it promotes is itself a correlate of enhanced fitness in the current environment. Forms favored by these four forces will tend to be functional and, like selection, have temporal trajectories that are controlled by adaptively salient characteristics of the environment.

Migration, in the absence of other forces, will favor whatever variants happen to occur among the populations from which migrants are drawn, whether these are stylistic or functional. Similarly, indirect transmission will cause increases in the frequency of whatever stylistic or functional variants happen to be encoded in the media on which it depends. Both these forces can be expected to cause directional changes in stylistic variant frequencies in recipient populations. Between initiation of either process and equilibrium, the resulting trajectories would resemble punctuated functional change under selection or selection-based learning rules. However, stylistic forms should be identifiable by the Markovian structure they exhibit before initiation of migration and after equilibrium is reached.

Consider finally patterning under simple indirect bias when there is no causal link between secondary variant and indicator variable (Equations 3.23-3.26). Given an initial correlation between the indicator variable and a suite of secondary traits arising from some other source, simple indirect bias will deterministically sort secondary variants, whether they are stylistic or functional, until equilibrium is reached. Consider, for example, two segments of a single randomly learning population with opposite values of some dichotomous indicator variable. Simple indirect bias will cause changes in secondary variant frequency in one population segment, driven by the operation of any other evolutionary forces, to influence variant frequencies in the other segment. Changes affecting the segment characterized by the favored indicator characteristic will be more influential, but just how much more influential is a function of the indirect bias parameter. When the value of the parameter approaches one, the population segment characterized by the disfavored value of the indicator variable will simply track changes in secondary variant frequency in the population segment characterized by the favored value. Hence when there is no causal connection between secondary variant and indicator variable, expectations concerning temporal trajectories of stylistic and functional variants must be based on the other forces discussed above.

In this discussion, we have glimpsed the problem of equifinality in expectations of temporal patterning of stylistic and functional variants in two places. Functional variant trajectories under the Red Queen may resemble stylistic ones governed by drift (e.g. Binford 1989:53). On the other hand, stylistic variant trajectories under migration and indirect transmission may resemble functional ones caused by selection and selection-derived learning rules. As we have seen, in both cases closer examination of patterning might help distinguish these two possibilities. However, it is important to realize that attempts to distinguish between stylistic and functional traits solely on the basis of their temporal patterns may still produce ambiguous results. This should not be surprising. As Sober points out, equifinality is a common deduction in theories of forces (1984:260). There are two solutions. The first, experimental manipulation, is denied archaeologists. The second takes advantage of source laws, in this case source laws for selection and selection-derived learning rules. Recall that source laws for selection specify matter-energy cost entailments arising from the behavioral implementation of different kinds of cultural variants in certain environmental circumstances. They indicate what cultural forms are likely to be adaptive, how, and when. Source laws for forces based on the operation of learning rules summarize the conditions under which the rules are likely to favor acquisition of certain forms. In both cases, source laws offer independent clues as to whether and how forms are likely to be functional. They thus offer a means of testing hypotheses about style and function initially derived from considerations of pattern. Alternatively, hypotheses concerning the functional status of forms derived from source laws may be tested against pattern predictions derived from consequence laws. This interactive process makes it possible to strengthen inferences about whether forms are stylistic or functional by successively testing them against predictions derived from both sources.

In fact, source laws have figured covertly throughout the foregoing discussion. Following Dunnell, I have noted the role of adaptively salient environmental parameters in controlling the distribution of functional variants. For this insight to be inferentially useful, we need to have some guidance concerning which of a very large number of environmental parameters are relevant in a particular historical situation and which variants they are likely to affect. The requisite guidance comes from source laws.

4.1.3 Effects of Evolutionary Forces on Stylistic and Functional Variants

The identification of which variants in a social-learning population are stylistic or functional, and a record of their temporal trajectories, together make it possible to make some initial inferences about the kinds of processes responsible for the trajectories. One basis for such inferences lies in the fact that some evolutionary forces can be expected to cause changes in either stylistic forms, or functional ones, or parallel changes in both. These expectations, drawn from the foregoing discussion, are summarized in Table 4.1. Change limited to functional variants is the result of selection, guided variation, direct bias, or complex indirect bias. The effects of drift, on the other hand, will for the most part be limited to stylistic variants. The qualification is necessary since sampling error may overwhelm modest fitness differentials and thus defeat the expected outcome of selection if populations are sufficiently small. Note that while other forces affect stylistic variant frequencies, drift is the only one that sorts them exclusively. On the other hand, parallel change in both stylistic and functional variants is caused by both migration and indirect transmission. Finally, although simple indirect bias affects frequencies of both stylistic and functional variants, their temporal patterning is determined by other forces.

A glance at Table 4.1 indicates that problems with equifinality will bedevil attempts to test hypotheses about forces on the basis of whether change in stylistic or functional variants or both is observed. Once again, some progress can be made with a dual approach that combines more detailed development of the implications of various forces for patterns and the search for sources that might be responsible for the forces whose identification is ambiguous on the basis of pattern alone.

Force	Effect	
Introduction of Variation	Functional Variants	Stylistic Variants
1. Migration	X	X
2. Indirect Transmission	X	X
3. Guided Variation	X	
Sorting		
1. Direct Bias	X	
2. Selection	X	
3. Indiect Bias	X	X
4. Drift		X

Table 4.1 Summary of the effects of different forces on stylistic and functional variants.

Guided variation, direct bias and complex indirect bias tend to sort functional variants in a manner that will roughly match the expectations offered above for selection in terms of trajectory shape. To the extent that the learning rules on which they are based yield accurate results, correlations with adaptively important environmental alterations will obtain as well. How might we hope to distinguish the operation of these three forces and selection? Two possibilities present themselves. First, all of these forces, except guided variation, depend upon the existence of prior cultural variation. This is reflected in the sigmoid shape of the variant trajectories that the three forces cause, although this would be difficult to monitor empirically. However, if variants can be shown to have existed in a population before they were driven to high frequency by a force, then the force responsible is probably not guided variation. Difficulties with sampling low-frequency variants prevent the inference from going the other way. Second, there may be differences in the time scales over which rule-based sorting and selection typically operate. Accurate and efficient learning rules can cause nearly instantaneous shifts in favored variants. Similarly rapid changes under selection demand selection coefficients that may be impossibly large, even when transmission is horizontal and differential teaching and learning rates are not tied to generational turnover. Source laws also offer a means to reduce ambiguity associated with selection itself and selection-derived learning rules. Particularly helpful in this regard will be the fruits of evolutionary research programs explicitly aimed at producing a catalogue of human learning rules and the conditions under which they operate (e.g. Cosmides and Tooby 1987).

Equifinality is also a potential problem in the case of migration and indirect transmission. Both these forces can be expected to cause correlated change in stylistic and functional traits. One difference that might be exploited to distinguish them resides in the fact that indirect transmission is likely to result in transfer of only limited portions of any individual's cultural repertoire, although migration necessarily entails the introduction of the suite of variants behind complete behavioral phenotypes. Again, additional help in discriminating the two processes may come from source laws that might guide the search for evidence of conditions favorable to movements of people on the one hand or artifact exchange on the other.

A factor that complicates this picture considerably is the possibility of error in the application of learning rules. Style and function are defined in terms of the expected effects of the model set formation component of the learning process, not the transmission component. It is an empirical matter whether or not forms favored by biased transmission are in fact fitness enhancing, given transmission structures that fixed the rules. Since all deterministic sorting is not immediately caused by selection, although selection is ultimately responsible for the rules, biased learning may cause departures from the expectations outlined above, based on fitness values of variants. Three areas may be distinguished. The first, simple failure of the rules to identify selectively superior variants is not problematic since selection will do the sorting in any case. The other two sorts of mistakes are less benign in terms of inference. The first is bias in favor of stylistic variants that the rules mistake for functional ones. Second, biased learning errors may favor forms that lower fitness. The possibility that bias may overwhelm countervailing selection pressures is increased when transmission structures are horizontal. Mistakes in learning rules will therefore lessen the accuracy of hypotheses based on consequence and source laws cast in terms of ultimate fitness effects. Here again increased knowledge of the content of human learning rules is the key to improvement. However, since rules are the outcome of a history of selection, a considerable amount of variability ought to be accounted for correctly in hypotheses cast in terms selection and transmission structures alone.

The foregoing is not intended as a complete account of problems we are likely to encounter in making inferences or of the means to cope with them. Real historical processes, by their very nature, are likely to be the outcome of unique combinations of multiple forces and historical contingencies. Hence the particular route by which inferences are made is likely to vary from case to case. Inferences about real-world situations will be based on complex models that combine several of the simple models outlined in the previous chapter. Consider for example migration. The trajectory of adaptively important behavioral variants of immigrants entering a novel environment will be affected not only by the relative frequencies and migration rates of Equation 3.9, but also by one or more of the forces that cause deterministic sorting in that environment. What I am advocating is a strategy for inference, based on using the simple models described in the previous chapter as guides for building hypotheses about complex historical process. I hope to have illustrated how making inferences about the forces responsible for a particular historical situation requires both source and consequence laws. It is a matter of testing hypotheses against expectations derived from each area of theoretical concern against one another. I have tried to suggest what those expectations might look like in some particularly simple cases.

Fundamental to the discussion has been the style-function dichotomy. Because stylistic variation is caused by the random exigencies of drift and random variation, it is independent of environmental contingencies. It is the means of choice for measuring continuity within and historical relationships between social-learning traditions. Style is the means by which we can determine who talked to whom and enquire into the various processes by which communication is effected. Functional variants, are tied to environmental changes via the fitness differences they engender in individuals. Functional variation is the key to understanding how individuals sustain themselves as members of social-learning populations and how they make more individuals who are similar to them in functional terms.

4.2 Patterning in the Archaeological Record

The archaeological record is not simply a census of variant frequencies in a population. However, each of the above evolutionary processes is expected to affect the temporal distribution of artifact classes monitored in the archaeological record. Cultural variants inform artifacts and the behaviors in which artifacts play a role. Artifacts have characteristic discard rates depending upon the activities in which they are employed. Artifacts from chunks of time of variable length are assembled in deposits. Finally, assemblages of artifacts may be derived not from an entire population, but a small portion of it, or only a single individual. In this section I briefly suggest how each of these effects might be modeled and their implications for temporal patterning in the record using the computer simulation of drift. I concentrate on drift for two reasons. First, the simulation offers a conveniently concrete means to illustrate these additional effects. Second, the generalizations about stylistic variant trajectories that include these effects will turn out to be old friends to archaeologists and the basis of archaeological inference for the past 70 years.

4.2.1 Discard Rates

Both the deterministic models and the simulation of drift described briefly in the previous chapter dealt only with the frequency of variants in the heads of population members. However, the frequency of types or modes of artifacts in the archaeological record is a function not only of the frequency in a population of cultural forms prescribing artifact morphology, but also of two additional ingredients. The first is the rate with which the behaviors associated with a given artifactual form are executed. Each individual's cultural repertoire, includes not only instructions prescribing artifactual forms, but also prescriptions for how behaviors involving different kinds of artifacts are to be executed. Since these behavioral instructions specify the circumstances under which particular behavioral performances are appropriate, they determine the frequency with which variant behaviors with variant artifacts are performed. Artifactual variants are thereby associated with characteristic use frequencies. The second ingredient is the probability that a given artifactual variant will fail, be lost or discarded during a given use or period of use. This is determined jointly by the properties of the artifact and its culturally prescribed mode of use. The product of use frequency and failure probability is a discard rate associated with each artifact. Together population-wide frequency and discard rates result in a characteristic rate at which different types of artifacts enter the archaeological record (Ammerman and Feldman 1974, Schiffer 1976).

Discard rates are culturally determined. Thus their effects can be included in the simulation by adding to it a continuously varying cultural trait. The original discrete trait is construed as a dimension of variation for artifact form, while the continuous trait represents discard rates arising from behaviors associated with the artifactual variant. When a novel discrete variant appears, it is assigned a discard rate chosen from a uniform distribution ranging from 1 to 10. Learners acquire their discard rate value and their discrete variant from the same model. Innovation in the continuous trait is handled through a variance parameter that controls error in the learning process: the value learners acquire from their models is equal to the model's value plus a value picked from a normal distribution with mean 0 and standard deviation 1. There are reflecting barriers at discard rates of 1 and 10. This represents the fact that negative discard rates are impossible and the amount of time and energy individuals can waste in stylistic behavior is limited by selection and selection-derived learning rules. With this scheme the frequency of a form during a time period is a function of both its popularity in the population and the culturally conditioned discard rates associated with it. The frequency with which a variant is represented in a given time period is the sum of its discard rates

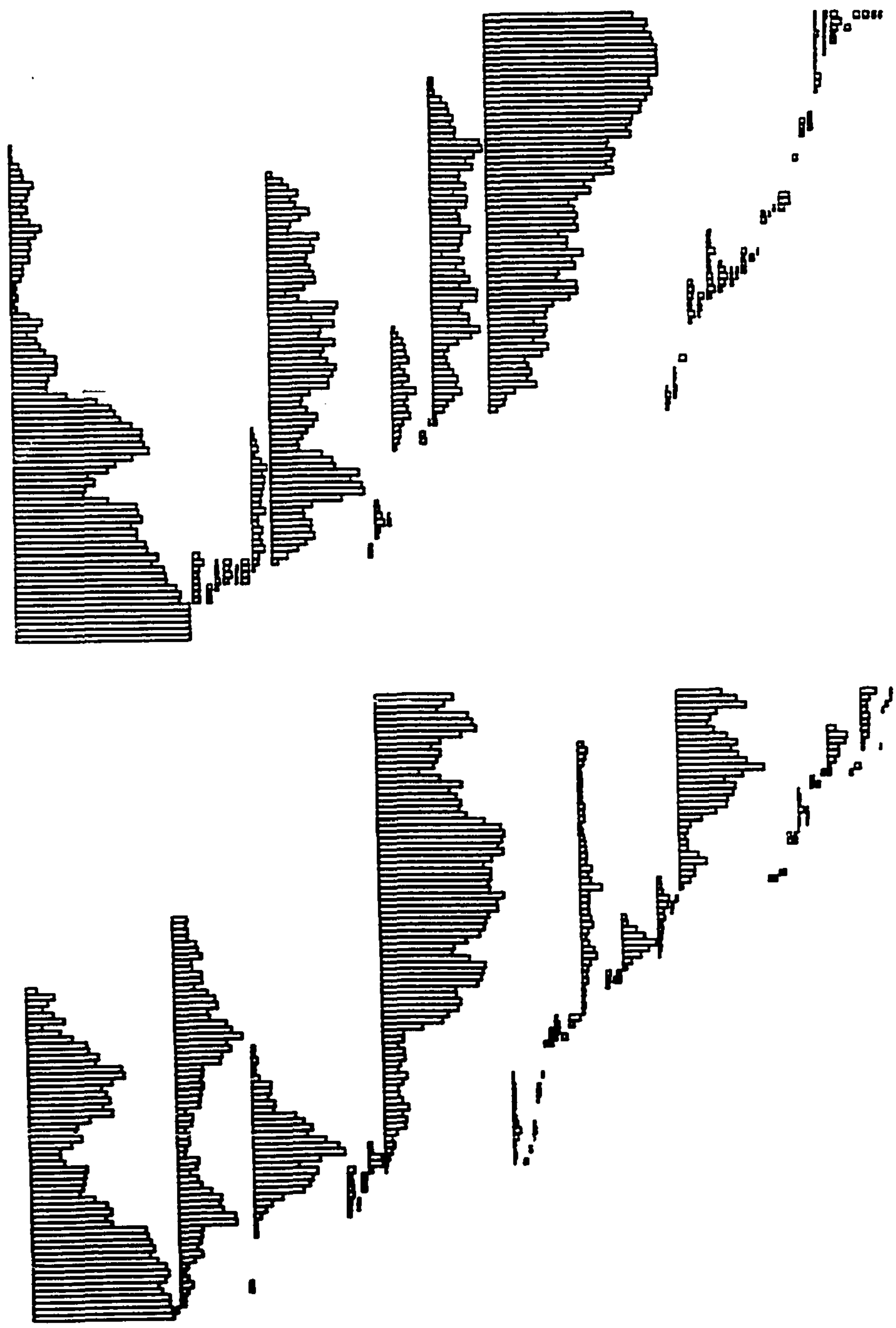


Figure 4.1 Two examples of the trajectory of change in variant discard frequency under drift: N=50, innovation rate=.01, 100 time periods.

across individuals. The resulting changes in frequency can be referred to as variant discard trajectories, to distinguish them from simple variant trajectories described in the last chapter.

Figure 4.1 portrays a typical realization of variant discard trajectories. The resulting shapes look very similar to variant trajectories of the previous chapter. Just how similar the two are may be measured with the help of the two trajectory shape statistics, CG and UNI. Figures 4.2 and 4.3 show CG and UNI respectively for variant discard trajectories as a function of variant duration. The same dependance on duration previously observed for simple variant trajectories emerges for the discard trajectories. After about 30 time periods, the negative correlation with duration disappears. Values of CG for variants whose durations are greater than 30 average .522 (s=.069). The mean for UNI is .403 (s=.065). Note that both the means and standard deviations are nearly identical to the values obtained for simple variant trajectories. In both cases expected shape of variant frequency through time is lenticular, with center of gravity in the middle, and reversals in frequency between origination and maximum and maximum and termination. In other words, when the process is observed at the population level, alteration of the simple variant frequency model of drift to include discard rates produces no changes either in expected temporal patterning or in variation about that expectation.

To see why this is the case, we need to consider the dynamics of discard rates for a single discrete variant more closely. Initially all population members start off with the same value. However, despite the fact that variation introduced into the population is normally distributed, the variant-specific, population-wide rates quickly reach an

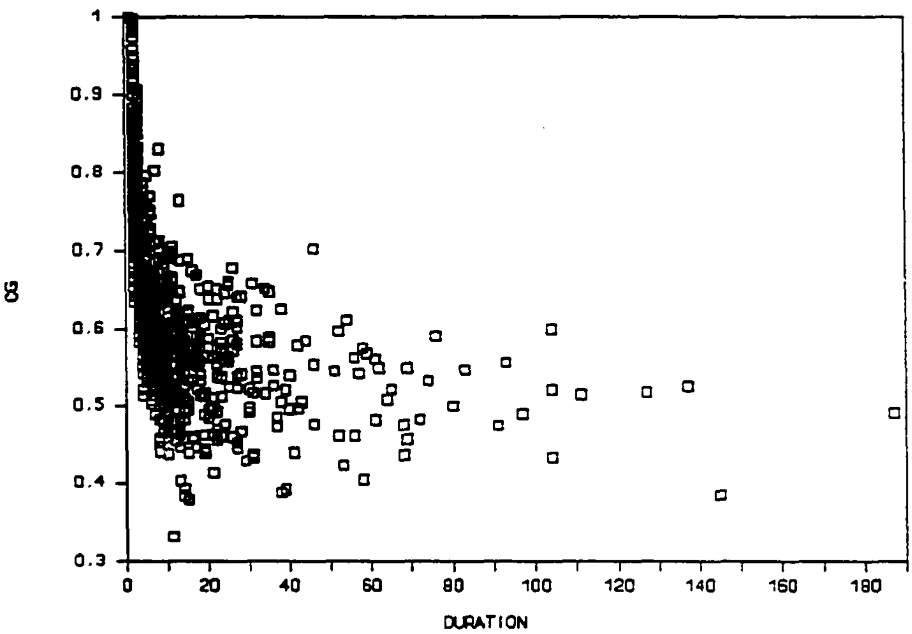


Figure 4.2 Values of CG for variant discard trajectories as a function of duration, generated during 20 simulation runs: N=50, innovation rate=.01, 200 time periods. Only variants originating and terminating during simulations are included.

equilibrium uniform distribution whose limits are the reflecting barriers. Discard rates for individuals are a random walk within these limits. Discard rates thus add a noise component to the expected trajectories of variants. However, when discard rates are summed across all individuals with a given discrete variant to yield population-wide discard frequencies for that variant, the noise component is weakened. Individual deviations from the expected discard rate, the midpoint of the uniform distribution, cancel one another out. The fact that frequency is monitored at the population level means that individual variability in discard rates associated with a given variant is attenuated.

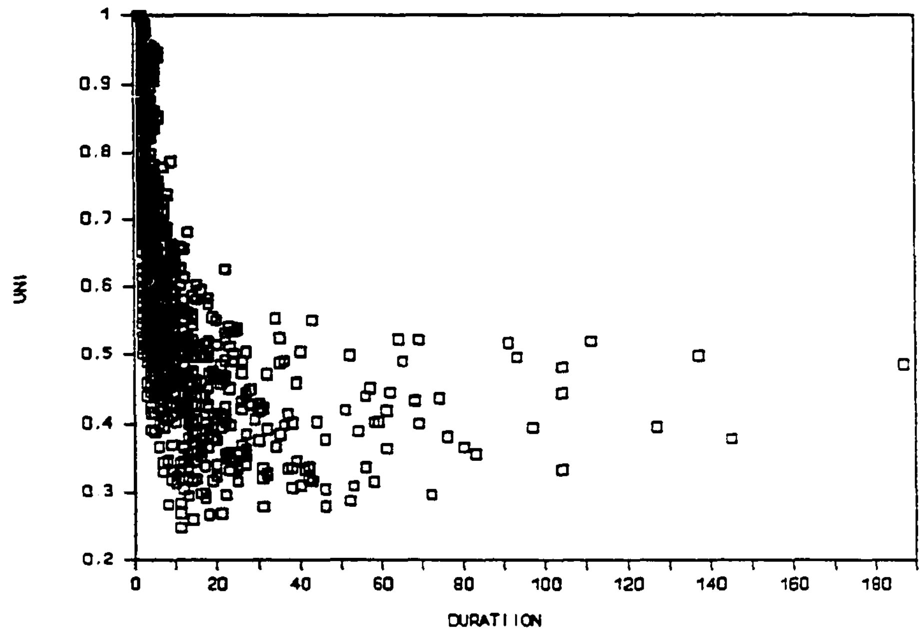


Figure 4.3 Values of UNI for variant discard trajectories as a function of duration, generated during 20 simulation runs: N=50, innovation rate=.01, 200 time periods. Only variants originating and terminating during simulations are included.

In the case described above, individuals learn discard rates from only one model. However the results are essentially the same for other transmission schemes, although the details differ. Consider blending cultural transmission of continuous variants. In this case individuals would learn discard rates by averaging the rate values of two or more models who possessed the discrete variant that they learned (Boyd and Richerson 1985:74). Under blending inheritance, discard rates associated with a given variant become normally distributed in the population. Because blending inheritance destroys variation, the equilibrium variance equals the innovation variance. Hence stochastic fluctuations in the discard rates among individuals would be dramatically dampened, compared with the scheme described above. Again the expectations derived for simple variant trajectories would hold.

4.2.2 Individual Repertoires

So far our results have been presented solely in terms of the frequency of variants in a population. Often, as in the example I will describe later, we have access to assemblages derived from a single household. Hence it is useful to consider what the trajectory of change for a single individual might look like. Figure 4.4 portrays the history of occurrence of a single variant and its discard rate values in the repertoires of 10 individuals. These individual histories are drawn from same realization of the simulation whose population-wide outcome is figured in Figure 4.1, top, and the variant whose individual-level history is depicted is the initial variant from that run. Note that the variant appears discontinuously in individual repertoires. This feature is a necessary, and up to now unremarked, consequence of horizontal transmission when there is variation for any cultural trait in a population, no matter what evolutionary force may be at work. Thus it has been covert a component in all the models discussed to date.

This feature is congruent with the understanding of social learning as a two-step process developed by social-learning theorists (e.g Bandura 1977, Boyd and Richerson 1985:42) and in the literature on mathematical models of diffusion of innovations (Cavalli-Sforza and Feldman 1981:34,49-50). Both distinguish an awareness phase, in which learner's initial attention to a novel variant is followed by rehearsal and cognitive

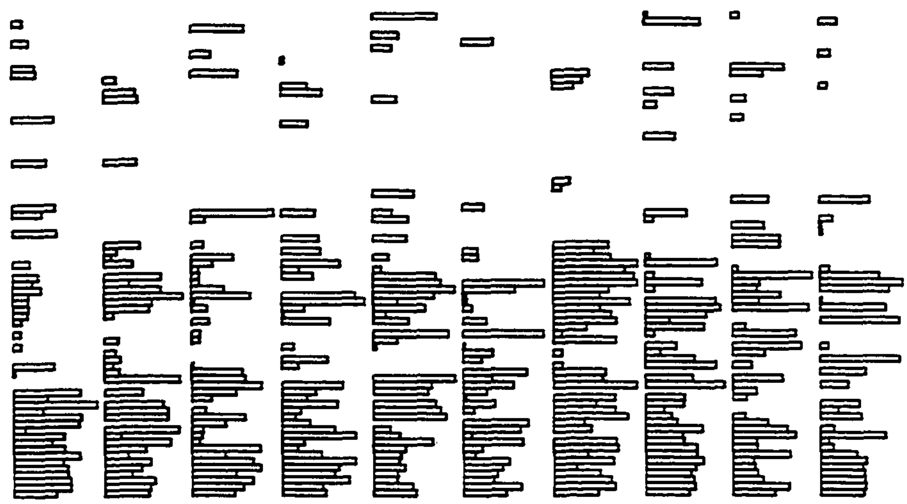


Figure 4.4 Occurrence over time of a single variant and its discard rate in the repertoire of 10 individuals. Bar lengths measure rates. Gaps represent adoption of an alternative variant.

reorganization leading to retention of the variant in memory, and an adoption or performance phase in which individuals incorporate the variant into their active behavioral repertoires. The discontinuous distribution of variants in individual repertoires, implicit in all horizontal transmission models and revealed in the simulations, can be understood in these terms. The initial appearance of a variant in an individuals's repertoire represents both awareness of the form and his adoption of it, that is the decision that it is actually a good idea to implement the variant in behavior. Subsequent appearances represent re-adoptions after a period during which an individual temporarily adopted an alternative variant, but remained aware of the first variant.

The important thing to note is that the density in time of adoption and use of a single variant in the repertoire of an individual are controlled by the overall frequency of the variant in the population at large. When the variant is popular, it is found frequently in the active repertoire of a single individual. When a variant is rare, individuals rarely opt for its behavioral implementation. Discard rates -- represented by the height of the bars -- inject an element of noise that in this case is not dampened by averaging across multiple individuals.

4.2.3 Time Averaging

Archaeologists monitor evolutionary patterns of behavioral phenotypes in assemblages of artifacts. Although there is an occasional catastrophic event like Pompeii, the vast bulk of the archaeological record is comprised of assemblages that are the result of attritional processes operating over intervals of time (Binford 1981). Because the content of attritional samples is the product of a process partially controlled by rates of discard, such samples are necessarily time-transgressive. As the interval over which the attritional sample accumulated goes to zero, so does the size of the sample. The frequency of an artifact type in an attritional sample is thus a function of the mean discard rate for that type over the interval during which the sample accumulated. Hence attritional samples may be said to be time averaged.

Two parameters are especially important in determining the character of the time averaging process that creates attritional assemblages: assemblage acuity and spacing. These parameters are set in turn set by the nature of the taphonomic processes, both cultural and non-cultural (Schiffer 1976:14-15), responsible for the creation of the archaeological record. Thus a simple way in which to think about the impact of formation processes on evolutionary patterns is in terms of variability in assemblage spacing and acuity. Acuity refers to the amount of time over which an assemblage accumulated (Behrensmeyer and Schindel 1983) or, more precisely, as the variance of the probability density filter that describes the time-averaging process. Spacing, on the other hand, is simply the amount of time separating sample intervals, or more precisely their end points.

Expectations concerning patterning in the archaeological record of discard trajectories depend upon acuity and spacing of the samples in which they are monitored. Clearly matters are greatly simplified if acuity and spacing are constant across a set of samples. Under these conditions, if acuity is sufficiently low that samples average over intervals that include multiple transmission episodes, the time periods of the recursion equations and the simulation, the resulting archaeological discard trajectories for individuals will mirror population-wide variant frequencies. A example is provided in Figure 4.5, which shows the result of averaging discard rates of a single variant in the repertoire of 10 individuals over 10 time periods. The patterning is the same as that exhibited at a population-wide level by the same variant in Figure 4.1, top.

Under these conditions, the overall shape of an archaeologically monitored trajectory is largely determined by the density of occurrence of the variant in the repertoire of an individual, even when, as in this case, discard rates are allowed to vary over an order of magnitude. This is an interesting and initially non-intuitive result. It

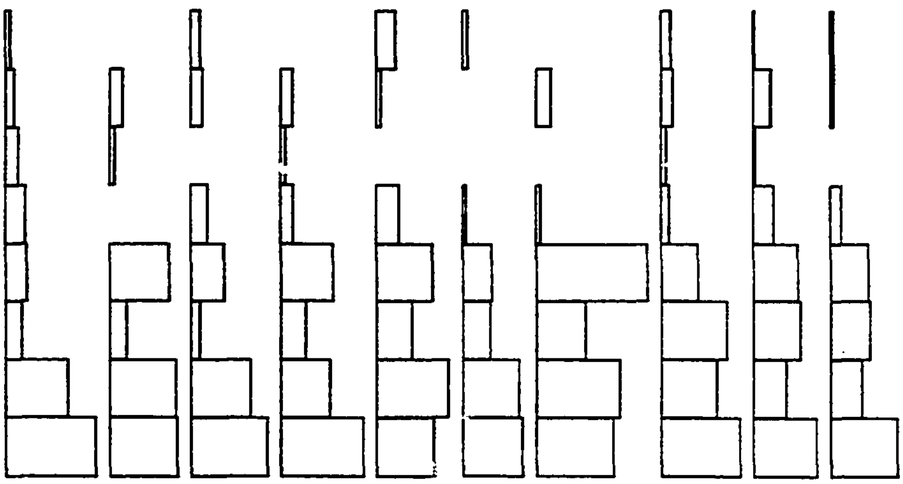


Figure 4.5 Discard rates of a single variant averaged over ten time periods in the repertoire of the same 10 individuals shown in Figure 4.4.

implies that any expectations for dynamics generated for simple variant trajectories on the population-wide level can be applied to discard trajectories in individual behavioral repertoires, when the latter are monitored through the time averaging effects of archaeological formation processes.

The results of actual archaeological samples will be a bit more noisy than those depicted here. Recall that the model results are based on discard rates, the parameters controlling the discard process. Real archaeological assemblages are sampled from this process. Hence their contents will be affected by sampling error. Problems in documenting patterning archaeologically will arise when the reflecting barriers on real discard rates are very low and, as a result, the corresponding artifact type rarely enters the archaeological record. In such circumstances, difficulties are compounded when the record available is the product of the behavioral repertoires of a small number of individuals. If discard rates are sufficiently low, then artifacts will not occur with sufficient frequency to allow accurate estimation of the density in time of the cultural variants prescribing their use.

From an evolutionary perspective, emphasis on formation processes of the past decade is an important advance. However, evolutionary models define what aspects of formation processes are important. Emphasis needs to be placed on estimating acuity and spacing of assemblages, not on tracing the taphonomic histories of individual artifacts comprising them (cf. Schiffer 1983, 1976:42-57).

4.2.4 Multiple Traits

Two final complications can be introduced into the drift simulation, intended to capture the multidimensional character of archaeological typologies. So far each simulation has tracked only a single dimension of variation. However, archaeological typologies typically measure many dimensions at once. Thus we need to consider simultaneously the results of the transmission of several traits or variables. Second, we have kept track of all variants generated for a single dimension of variation. Yet only the artifactual traces of the most successful are found in the record and recognized in the typologies we use to measure it. These additional features can be incorporated by tracking the transmission of several traits, ten in this case, at once. After 100 time

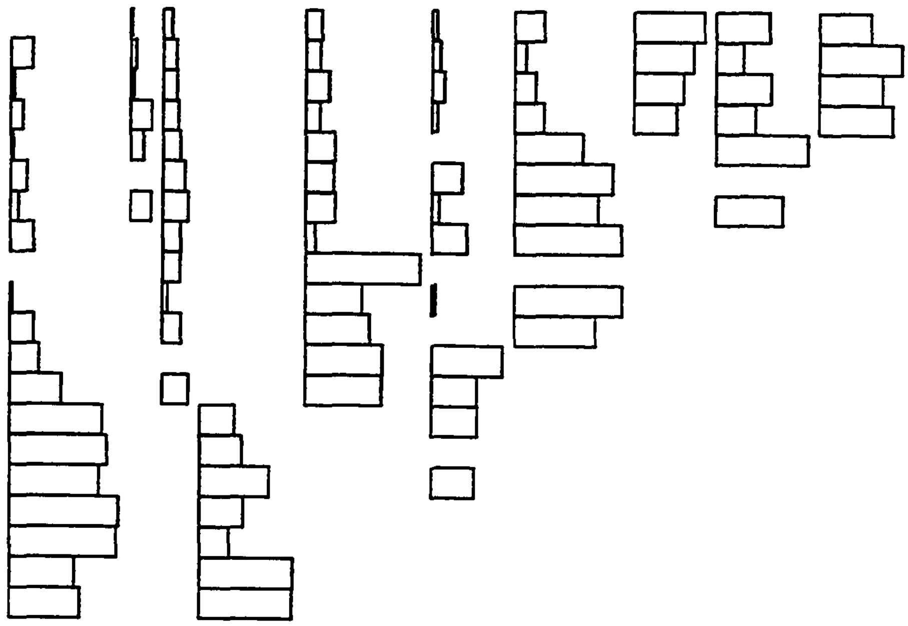


Figure 4.6 Variant discard trajectories in the repertoire of a single individual, time-averaged over 5 time periods.

periods, I determine for each trait which variant was the most successful, that is which variant over the course of the entire simulation had the discard rate summed over all periods it was present in the population. The frequencies of the most successful variant for ten traits are recorded. The result portrays the patterning we might expect in archaeological assemblages categorized in terms of dichotomous dimensions of variation, all of which are stylistic (e.g. Rouse 1939). More generally, it is intended to approximate assemblage patterning in time captured by any classification device based on multiple dimensions. Since I will be dealing with the remains of a single household, here I present the results for contents of a single individual's stylistic repertoire, measured with time averaging. A typical outcome is shown in Figure 4.6.

The shape of individual variant trajectories is familiar and requires no further comment. However, it is useful to consider the implications for archaeological patterning from another viewpoint, by measuring the similarity between assemblages. This means of characterizing assemblage variability can be helpful when we lack a sufficient number of samples scattered across a long enough span of time to be able to assess the shapes of trajectories from origination to termination. I have computed Manhattan distances between periods in the space of variant trajectories and reduced them via multidimensional scaling to two dimensions so they can be inspected on paper (Figure 4.7). Three aspects of the patterning that emerges from this analysis are particularly noteworthy. The first is an artifact of the simulation: there tends to be clustering between assemblages from successive time periods before equilibrium is reached. Second, note that the assemblages lie on a nonlinear curve in the reduced space of the ordination. This is the expected outcome since the variants in the simulation exhibit a pattern of successive replacement through time (Wartenburg et al. 1987). Finally, after equilibrium is reached, at which the number of variants in the system is more-or-less stable (see Equation 3.38), the distances between assemblages from successive time periods tend to be about the same.

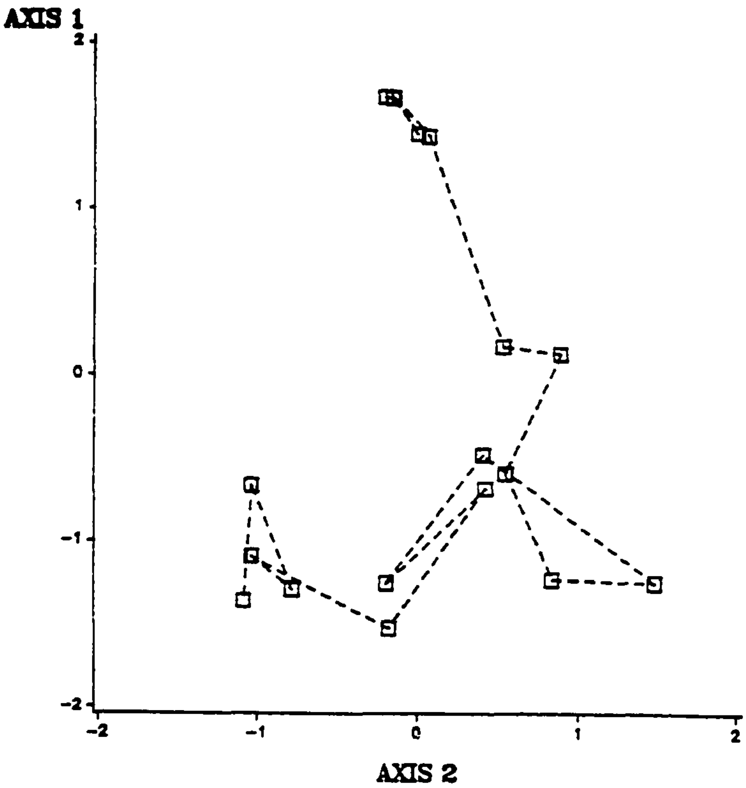


Figure 4.7 Ordination of successive time periods portrayed in Figure 4.6 obtained by multi-dimensional scaling of Manhattan distances among time periods.

4.2.5 Frequency Seriation

Dunnell (1978) noted the similarity between the Gould et al.'s (1977) clade diversity diagrams and the battleship-shaped curves that archaeologists have long used as the basis for chronological inference in frequency seriation. The ideal curve described by the seriation model tends to increase monotonically from origination to a maximum and then decrease monotonically to disappearance (Wissler 1916, Spier 1917, Rouse 1967, Dunnell 1971). It lacks the short-term reversals in direction evident in the drift simulations. However, note that the variant trajectories from the simulations become increasingly monotonic as the variant frequencies for several successive time periods are averaged together. The larger the number of time periods included in a sample, the smoother the trajectories become. Cultural drift, monitored archaeologically through the filter of time-averaging formation processes, provides a mechanistic explanation for generalizations about the shape of trajectories of stylistic variants on which seriation depends. Clearly this implies that chronological variability among assemblages characterized in terms of style would most closely approximate the monotonic frequency seriation model when those assemblages were derived from communities of multiple individuals, or were the result of large amounts of time averaging, or both. Surface-collected ceramic assemblages from village sites share both characteristics. It was on precisely this sort of material that frequency seriation had its initial (Kroeber 1916, Spier 1917) and enduring (e.g. Phillips et al. 1951) successes in solving the problem of chronological inference.

With recent application of multivariate techniques to the execution of seriations, attention of practitioners has shifted from the shapes of variant trajectories to the examination of distances among assemblages. The hope has been that distances between assemblages in multivariate space are a linear function of their temporal spacing (e.g. Marquardt 1978). However, no attempt has been made to offer an explanation for why such a relationship might obtain. The drift simulation provides one. In addition, it suggests the conditions that are necessary for the existence of the relationship. These are constant population size and innovation rates, on the one hand, and constant temporal acuity of assemblages on the other.

4.2.6 Other Forces

Although this discussion has been cast in terms of drift, its results can be applied with little alteration to the other evolutionary forces under horizontal transmission. The main area of contrast lies in the fact that for functional variants, whose frequency in a population is likely to be controlled by selection and selection-derived learning rules, the values of the associated discard rate variable will be determined by the same forces. Hence discard rates will not random walk. Rather, their trajectories will be controlled by changes in adaptively salient aspects of the environment. The earlier discussion temporal patterning of functional variants will apply. In other words, we can expect either stability interrupted by punctuations or clines in discard rates depending on the pace of environmental change.

4.3 Artifact Morphology and Behavior Again

The drift simulation has made plain the need to incorporate behavior, manifest in discard rates, into models used in archaeological inference. In this section I pursue behavior further. In the first two chapters, I described a distinctive functional-morphological approach to the inference of behavior from the archaeological record (Sections 1.3.2 and 2.2). I suggested that behavioral inferences made using this approach were best seen as hypotheses that drew on both source and consequence laws. The source-law component was a kind of optimality argument which developed physical consequences of form-behavior combinations and ranked them on some fitness-related scale. The consequence component was responsible for specifying the scale in the first place. It also described the mechanisms that translated the ranking into the co-occurrence of the optimal form-behavior combination. The models of evolutionary forces presented in Chapter 3 provide the tools with which to further clarify just how this last component of functional morphological inference works. They make it possible to model the processes whereby deterministic forces, resulting from selection or biased learning rules, cause predictable associations between form and behavior. The correctness of any functional morphological inference depends on the existence of these processes.

Consider, for example, a functional morphological hypothesis with selection as the force responsible for the link between form and behavior. Like those grounded in the action of other forces, all such hypotheses treat at least two culturally transmitted traits, one representing a dimension of behavioral variation, the other a dimension of variation in artifact form. In the discussion to follow I assume both are dichotomous traits taking values c/d and e/f respectively. An alteration over time in the frequency of the morphological variants can be documented archaeologically. The goal of inference is to produce an hypothesis that at once specifies change in the behavioral variant that accompanied it and offers a mechanistic account of the process by which it occurred. This requires that fitness values can be assigned to each of the four form-behavior combinations, based on the source-law component. Just what the resulting temporal dynamics look like depends on the messy details of cultural transmission, in particular the extent to which learners learn their morphological and behavioral variants from the same model, and the relationships among fitness values of those combinations.

To simplify the first of these issues, consider the two extreme cases. The first extreme is depicted in the zero-force law for two cultural traits (Equations 3.18-3.21). It showed how random social learning destroys between-trait correlations, pushing variant combinations to linkage equilibrium, where they occur independently of one another. In this case learners acquire each trait independently. They learn traits from the same model only by chance. At the other extreme is the learning rule used in the drift simulation, where individuals were constrained to learn both their discrete variant and the continuous variant describing discard rates from the same model. In a simple model for two dichotomous traits, this learning rule preserves correlations between variants: the frequencies of the four possible trait combinations are constant if no other forces intervene. In the first case, there is no linkage between the traits. In the second, linkage is complete.

Consider next the relationships among fitness values of the variant combinations. The evaluation of physical consequences like that described in Table 1.1 implies that fitness values of ce and df combinations are greater than the values associated with de and cf. Furthermore, in the current environment, it is hypothesized that the fitness of ce is greater than that of df. This pattern of inequalities among fitnesses can be made more precise by assuming the relationship among fitness values is additive (Table 4.2) (e.g.Crow 1986:105).

		Morphology e	f
Behavior	c	1+s	1-s
	d	1-s	1

Table 4.2 Hypothetical additive relationships among fitness values for 4 behavior-form combinations.

When fitnesses are additive and there is no linkage, the trajectory of change in the system can be predicted by combining Equations 3.18-3.21 and Equation 3.32 into a system of four linked recursions and substituting the fitnesses given in Table 4.2. Whether or not the fittest form-behavior combination is fixed in the population depends upon the starting frequencies of the variants. For example, when there is no correlation in the occurrence of traits across individuals, a population initially dominated by the df variant combination will become fixed for it, despite the fact that the ce phenotype is the fittest.

On the other hand, when individuals learn both their behavioral and morphological variant from the same model, no such complications arise. In this case the four recursions are simply derived from Equation 3.29 alone and the dynamics are equivalent to those for four alternative variants for a single cultural trait. In this case the optimum form behavior combination is guaranteed to increase in frequency.

The contrast in outcomes in these two cases is well described in Sewall Wright's famous adaptive landscape metaphor, where elevation represents the mean fitness of the population and the x and y axes represent the marginal variant frequencies. When fitnesses are not frequency-dependent, selection maximizes mean fitness of the population. Hence selection will push the population up to the top of the closest peak on the landscape. In a two-trait system, with additive fitnesses, there are two peaks and only one of them is a global optimum. The population may be trapped on the local optimum because transmission dilutes the frequency of the globally optimal variant combination faster than selection can increase it. Linkage transforms the topography of the adaptive landscape so that it has a single peak representing fixation of the fittest form-behavior combination. Since transmission does not lead to the disassociation of variants, the correlation between traits introduced by selection accumulates in the population (Crow 1986:104-106).

Without a learning rule creating linkage between traits, there is a possibility that the fittest variant pair present in a population may not be fixed. This suggests that inferential strategies that are not empirically grounded in documented change over time in the relevant dimension of morphological variation must be viewed as suspect. Given that a population is known archaeologically to be fixed for a given value of the morphological variant at only a single point in time, there is no guarantee that selection will have fixed the behavioral variant that is globally optimal given the current environmental context. On the other hand, when inference is based on an archaeologically documented change in morphological variant frequency, correlated with a change in environmental context, the results above suggest that it is unlikely that the population has ascended a locally optimal fitness peak. It is correspondingly more likely that the morphological change was accompanied by fixation of the globally optimal behavioral variant

That individuals do in fact tend to learn functional behavioral and morphological variants from the same model accords with common sense and theoretical expectation. Under conditions described above the mean fitness of a population employing such a rule is greater than the mean fitness of one without it. This implies that the linkage rule would be fixed in a population of social learners, some of which used the rule and some of which did not. To the extent that learners operate with a learning rule that instructs them to learn both behavioral and morphological traits from the same model, the overall predictions derived from the optimality component of a functional morphological argument will not founder on the messy details of cultural transmission. This is not to say that the consequence-law component is irrelevant. It still is crucial for the construction of source laws by defining the scale on which alternative variants are ranked, for offering an account of the causal process by change occurred, and for providing the means to test the hypothesis.

The case of ceramic sherd thickness, initially introduced in Chapter 1 to illustrate the functional morphological approach (Braun 1983), offers an example. Greater reliance on intensive cooking was the behavior inferred from the trend to thinner walled ceramics during the Late Woodland in the Midwest. This implies that the form-behavior combination of thin-walled ceramics and intensive cooking had greatest fitness in this environment. Independent evidence fills in some of the necessary details. Dietary reconstructions, based both on plant remains and bone isotope analyses, indicate an increasing importance of starchy seeds in the diet. The behavioral phenotype being selected for is efficient boiling of starch seeds. This form-behavior combination gave rise to fitness benefits in the form of higher fertility rates. Starchy seeds boiled as mush could be used as weaning food, enabling early weaning and decreased interbirth intervals (Buikstra et al. 1986). Under these conditions, if pottery construction and cooking methods were vertically transmitted, the hypothesized form-behavior combination would have swept to fixation via selection of cultural variation. Thus the empirical correctness of the behavioral inference depends upon the role of selection. A mechanistic exposition of the process that lies behind the inference suggests how it might be tested, for example by seeking independent documentation of the rel-tionship between sherd thickness and fertility, the latter expressed in household size, both within and among populations.

Selection, of course is not the only force that can cause the deterministic sorting that must be invoked in any functional morphological inference. An exhaustive account of the processes that might underlie legitimate behavioral inferences would include analogous treatments of direct bias, complex indirect bias, and guided variation. I shall not provide these treatments here. However, I do want to call attention to the implications of stochastic sorting for behavioral inference.

An evolutionary account of the functional morphological approach to behavioral inference has severe implications for the possibility of making behavioral inferences concerning stylistic forms. It implies that when there are no differential fitness consequences for various form-behavior combinations their frequencies will be determined by drift. Lacking the causal link between them, form and behavior are independent of one another both within and among populations. Thus behavioral inferences for stylistic forms are tenuous. Without direct evidence from observable behavior, there is little justification for the hypothesis that cups are for drinking tea and saucers for holding cups. To the extent that behavior with cups and saucers lacks fitness consequences, individuals might as well drink from saucers and wear cups on their heads.

4.4 Social Complexity and Evolutionary Forces

In the previous sections of this chapter I have been concerned with the relevance of various evolutionary forces to archaeological inference in general. I now narrow the scope of discussion to consider briefly how a subset of forces might interact as powerful engines of change within complex societies. This is a necessary step since the case study to which the remainder of this study is devoted is set in such a context. Two correlated characteristics of complex societies are especially important with regard to the operation of cultural evolutionary forces. These are social stratification and functional differentiation.

4.4.1 Stratification

By social stratification I refer to differential access to resources, translated into storable surplus and perpetuated across biological generations through inheritance of wealth among genetic relatives. As a result the distribution of wealth among individuals is highly skewed, with small numbers of individuals at the top of the scale and large numbers at the bottom. Systematic and large disparities in wealth among individuals provide a context in which indirect-bias learning rules become a powerful force affecting the distribution of both stylistic and functional variants. That wealth-based indirect bias rules are widespread is suggested by reports that wealth is a prestigious or admired characteristic in a wide variety of human social groups (Hill 1984, Betzig 1986). The existence of such rules is in keeping with theoretical expectations, given the observed correlation between wealth and Darwinian fitness within these groups, with the conspicuous exception of western industrial societies (Hill 1984, Borhgerhoff Muldur 1987b). This relationship provides the background conditions necessary for the fixation and maintenance of an indirect bias rule, transmitted along either genetic or vertical cultural channels, in which the favored indicator value is wealth or rates of wealth accumulation.

If cultural variants affect rates of wealth accumulation they will be subject to deterministic sorting by indirect bias rules. Individuals whose cultural repertoires cause decreases in wealth will be less likely to teach learners those causally efficacious variants because learners will be less likely to learn any variants from them. Conversely, individuals whose repertoires include forms that lead to increased rates of resource procurement will be more likely to teach learners who as a result will acquire greater amounts of wealth and in turn will be more likely to become successful teachers themselves. Culturally transmitted variants that affect wealth levels of individuals will be sorted deterministically.

The existence of strong indirect bias rules also has implications for the distribution of stylistic variants and the operation of drift. Recall that the amount of change in a single time period under drift was a function of number of individuals comprising the population. This result holds as long as each individual has equal importance in the transmission process. When this is not the case, that is when models have varying probabilities of teaching learners, then the amount of change under drift is a function of the effective population size, defined as the reciprocal of the probability that two randomly chosen individuals learned their current variants from the same individual (Crow and Kimura 1970:346). When individuals bring different weights to the transmission process, as is the case with indirect bias, the effective population size goes down. As the indirect-bias parameter approaches unity, the effective population size is simply the number of individuals with the favored value of the indicator variable. In this case, as we saw earlier, one segment of the population will simply track drift-driven change in the other. Given the skewed distribution of wealth among individuals, the favored segment is likely to be small. Hence the most influential population segment is also the one most likely to be the one most affected by drift.

Indirect bias has a second, similar effect as a function of the size of model sets, that is the number of models each learner encounters before learning from them. Under biased learning, the contribution of models with the favored indicator value scales with the size of a model set. Hence an increase in model set size has the same effect as an increase in the indirect bias parameter: it decreases the effective population size. Both these factors point to the conclusion that drift will be an important factor behind change in the frequency of stylistic variants in the cultural repertoires of participants in complex social systems, despite the fact that the actual number of individuals is very large.

However, we should not expect the stylistic contents of cultural repertoires of elite and non-elite groups to be identical. By definition stratification involves perduring differences among individuals in energy available to make investments necessary to translate cultural instructions into behavior. Thus wealth differences will affect the rate at which individuals incorporate variants of which they are aware into their behavioral phenotypes. Since the latter step makes variants available for observation and learning by others, there will be consequences for the dynamics of cultural transmission. Individuals with greater wealth will have higher "effective" rates of innovation and cultural transmission. In terms of the models of horizontal transmission in Chapter 3, elites will have lower values for A_1, the probability that a learner learns from itself, that is does not change its variant as a result of exposure to other population members.

Higher effective innovation rates mean greater amounts of stylistic variability. More transmission episodes per unit time will result in higher rates of change for stylistic variants. As a result of these processes, we can expect greater stylistic diversity and more rapid change in the stylistic repertoires of different social groups as larger energy surpluses available to them.

In addition to affecting overall rates of cultural transmission, stratification can be expected to alter the selective values of alternative variants of some traits. It is well known in evolutionary ecology that fitness values associated with a set of strategies may vary with the state of the organism adopting them. For example, foragers should accept greater amounts of risk from predation associated with different foraging options as energy reserves decline and chances of starvation increase (e.g. Houston et al. 1988). Similar effects can be expected in stratified human societies. The fitness consequences of variants will vary with the amount of energy available to the individual. Large energy investments required by certain cultural variants may have high positive fitness payoffs for elites, but negative ones for non-elites, either because the fitness penalties of making the investment or attempting to acquire the resources to make it would be to great for the latter group. Differential resource access means each group is in effect subject to different regimes of selection and other forces that cause deterministic sorting, each of that favors different variants. Alternatively, cost differences between alternative variants may have negligible fitness consequences for elites, but have significant ones for non-elites. In this case forces like drift, simple indirect bias, or indirect transmission might determine variant frequencies among elites, while deterministic sorting, via selection or bias, would control their frequency among non-elites. It is phenomena of this sort that offer evolutionary justification for archaeologists' attempts to measure assemblage variation in terms of the costs of manufacture or procurement of its components and then attribute variability on the resulting measure to variation in the wealth of its users (e.g. Feinman et al. 1981, Miller 1980).

4.4.2 Functional Differentiation

Functional differentiation adds several dimensions of complication to this picture. By functional differentiation I mean divergence among interacting individuals in ways of making a living (Wenke 1981:111-113, Earle 1987:64). Complex social systems are comprised of individuals occupying a wide variety of ecological niches, many of them based not on extracting a living directly from the natural environment, but from exchanges, characterized by variable degrees of reciprocity, among individuals.

Three effects of niche differentiation are relevant. First it promotes population structure, that is, non-random associations of individuals or groups whose members learn from one another more frequently than they do from others. Membership in such groups will likely be correlated with both spatial propinquity and wealth levels. Thus stylistic variability may be more complexly structured than the uni-dimensional cline implied in a model that incorporates only drift, indirect bias, and variable transmission rates. This additional complexity will emerge as a result of innovation and drift, taking divergent courses among sub-populations among which there is little communication as a result of functionally different adaptations. The correlation between stratification and functional differentiation means that individuals sharing wealth levels are also likely to have similar ways of making a living and hence learn from one another more frequently. When this is the case, stylistic differences among groups will be correlated with differences arising from different regimes of deterministic sorting arising from differences in resource access. The causes of divergence in the cultural repertoires of elites and non-elites will be very difficult to separate on the basis of empirical patterning.

The second consequence of functional differentiation is the potential for increased importance of indirect transmission. Unlike population structure, which promotes diversity, indirect transmission will decrease it. Indirect transmission is likely to be increasingly important given the increased pace of exchange of artifacts and information that accompanies functional differentiation. The repeated introduction of variants from donor groups, among whom exchanged artifacts or documents originate, into recipient populations, will cause the latter to resemble the former.

The third aspect of functional differentiation is the accompanying separation of producers of manufactured goods from their consumers. This is noteworthy here because archaeologists have supposed that variability in artifacts, especially stylistic variability, was exclusively referable to the repertoires of individuals who manufactured them (e.g. Plog 1980). This is only part of the process. On the production end, there are cultural instructions shared by individual artisans or artifact designers concerning such matters as the manner in which their products should be constructed and decorated. On the consumption end there are cultural instructions that determine whether or not consumers find certain shapes, decoration, or performance characteristics acceptable and that prescribe the behaviors in which artifacts, once acquired, are used. Assemblage variation at the local consumption level is a product of the interaction of both sets of instructions. However, consumer preferences are arguably more important since they determine the economic fate of producers of stylistically and functionally variable products. Composition of assemblages of acquired goods is a function of variability in socially learned instructions concerning acquisition and use among consumers.

The foregoing arguments can be summarized as follows. Despite large population sizes characteristic of complex social systems, drift can be expected to play a role in sorting stylistic variants within them. Both simple indirect bias and indirect transmission will cause large populations effectively to tract drift-driven change in a small elite population. Second, when there is causal interaction between an indicator variable and secondary variants, complex indirect bias will be an important force for sorting among functional variants. Third, both stylistic and functional variation will be manifest in domestic assemblages of artifacts, even when those artifacts were not produced by the individuals who consumed them. However because of the correlation between ways of making a living and the resources available to individuals, it will often be difficult to distinguish whether differences between groups are the result of divergent histories of deterministic or stochastic sorting.

This chapter brings to a close the predominantly theoretical portion of this work. In it I have tried to elucidate the manner in which evolutionary mechanisms necessarily figure in inferences concerning the meaning of variation in the archaeological record. In the three chapters to follow, I shall examine patterning in the archaeological record of the colonial Chesapeake with an eye to developing hypotheses about the evolutionary processes over the course of the first century or so of English settlement. The next chapter sets the stage with an overview of the settlement process. I pay special attention to the effects of asymmetrical transmission structures on deterministic sorting of cultural forms and culturally transmitted indirect-bias rules. I then turn to inferring the causes of the differential persistence of house plans documented in the archaeological record. The final two chapters are devoted to a case study in which the framework developed so far is used as the basis for inferring the behavioral aspects of architectural change at a single plantation and the evolutionary forces behind it.

Chapter 5

English Settlement of the Chesapeake

5 Introduction

With this chapter, I undertake a rapid shift of gears. So far the thrust has been almost entirely theoretical. Now I want to apply some of the ideas developed to elucidate selected aspects of the archaeological record generated by the English settlement of the Chesapeake during the 17th and early 18th century. This chapter introduces that subject.

First I outline how two current archaeological approaches to European colonization of the New World emphasize complementary aspects of environmental variation --local and global-- that would have affected colonial adaptations. However, they lack explicit consideration of mechanisms of change. I briefly outline, in a necessarily crude and preliminary way, how in the Chesapeake mechanisms for deterministic sorting might have worked. Temporal patterns in settlement spread and house plans provide examples of deterministic sorting of Chesapeake cultural repertoires induced by local and global causes respectively. The mechanisms behind the sorting of house plans are of special interest since the data exist with which alternative hypotheses concerning their character may be tested. I outline two hypotheses for the mechanisms that might have caused this kind of sorting and the conditions or sources that might have occasioned their operation. This lays the groundwork for the final two chapters, which employ the evolutionary framework developed so far to examine in detail the causes of sorting at a single site occupied from about 1670 to 1735.

5.1 World Systems and Frontiers

Two interpretive strands can be distinguished in recent work on the archaeological record associated with the global expansion of Europe, beginning in the 16th century, and in particular with the English colonization of North America. The first, largely derived from the work of marxist historians, attempts to understand behavior in regions dominated by Europeans in terms of the role those regions played in the origins and development of a "capitalist world system" beginning about 1450 (e.g. Paynter 1982). This system was based on an expanding division of labor among metropolitan or core states and peripheral regions that were often their colonies (Wallerstein 1974). Peripheral regions supplied raw materials, mineral wealth, and staple crops grown with unfree labor (indentured servants or slaves) to the core states. Unequal terms of exchange resulted in massive wealth transfers from periphery to core. The global system of economic specialization and the specific economic relations that constituted it are explained in terms of their contribution to European capital accumulation that eventually pushed Europe into industrialization.

The second strand is more exclusively focused on local change in peripheral areas -- frontiers-- occupied by European colonizers and their descendants (e.g. Lewis 1984, Miller 1984). The frontier literature has its theoretical underpinning in cultural evolutionism in the Spencerian tradition popularized in anthropology by Steward, White, and their followers. In this framework change in newly established colonial societies is seen as the result of adaptation of the colonizers to new environments (Thompson 1973). However, adaptation is here not the outcome of deterministic evolutionary forces like natural selection, but a developmental process alleged to have a predictable trajectory, driven by internal demographic processes. Change on the frontier is characterized by an initial simplification or impoverishment of cultural repertoires and social relations of colonists, caused by low population densities and attenuation of trade and communication ties with the "metropolitan" society from which they came. This is followed by a gradual increase in complexity over time, an increase described by the notion of colonization gradient. Although applicable to many other aspects of behavior, the colonization gradient is typically expressed in increases in size and complexity of settlement hierarchies and the transportation system connecting settlements. The gradient is duplicated in space, as settlement advances across a region (Casagrande et al. 1964, Lewis 1984:11-12). The prime mover responsible for the gradient in both its spatial and temporal manifestations is increased population density.

From an evolutionary perspective, both interpretive traditions are flawed. Discounting empirical problems (O'Brien 1982), the world-systems perspective's greatest liability is its highly teleological cast. Change in the periphery is explained in terms of the role it plays in the maintenance of a larger system, or the furtherance of that system's growth. Yet there is no account of the mechanisms whereby the distant effects in core areas of colonial activities shaped the course of the world system. The approach seems to take the post-hoc rationalizations of 17th-century state functionaries concerning why colonies were beneficial to their employers, rationalizations that go under the name of mercantilism, as the historical causes of local colonial processes. One secondary expression of this problem, the tendency of the approach to focus attention away from local processes of change, has been noted by some of its advocates (Paynter 1982:236).

The frontier approach is less teleological, but it too suffers from inattention to the mechanisms that cause the differential persistence of behavioral phenotypes in frontier environments. As a result the "laws" that power the approach emerge as empirical generalizations that describe the results of historical process. One expression of this shortcoming is stress on population growth as the only adaptively salient aspect of environmental variation (see below). Unique aspects of local ecology that may be far more important in shaping the trajectory of colonization are ignored. Thus not only are the generalizations unable to account for the differences that all concrete historical trajectories are bound to exhibit to one degree or another, they offer no theoretical motivation for their recognition. Far from offering explanations of anything, the generalizations about frontier process, like the "laws" of Spencerian cultural evolutionists, are simply abstract descriptions of phenomena that require explanation (Dunnell 1980, Popper 1964). In some cases, the departures are often so great, that the usefulness of the generalizations even as abstract descriptions is questionable. For example, Lewis regards the initial colonization stage of cultural impoverishment as an expression of the "principle that a generalized, non-specialized culture is more efficient for dealing with an extensive, relatively open environment" (1984:11). But who could imagine a more specialized niche than the staple monocultures of tobacco and rice that dominated the Chesapeake and the lowland Carolina respectively during the Colonial period?

The frontier and world-systems perspectives do have the virtue of calling attention to two complementary aspects of early-modern European colonization that must be attended in any successful account. The world-system approach makes plain that colonial niches depended to varying degrees on participation in exchanges in a trans-Atlantic economic system. It correctly suggests that shifting conditions in the Atlantic market had important effects on colonial behavior. On the other hand, the frontier tradition points to the importance of understanding change in the frontier context as the outcome of processes whose direction was affected by local conditions. An evolutionary perspective stresses the processes that cause change and thus offers a framework in which to integrate these two features. The world economy can be seen as altering selective pressures on the local level, opening new niches for individuals to exploit and closing others. The vagaries of supply and demand on a global scale were crucial environmental parameters affecting local processes. So too were ecological conditions that colonists found in the colony and the shifting adaptive pressures generated by the consequences of successful colonization, for example increases in population density. Processes of change must be understood in terms of the evolutionary mechanisms outlined in the previous chapter, mechanisms whose operation is conditioned by environmental inputs from both the world economy and local ecology.

5.2 Chesapeake Colonization Processes

This abstract argument should be made more concrete. A necessary step in that direction is to offer a complete account of the mechanisms that were responsible for deterministic sorting of cultural variation in the Chesapeake and that shaped English adaptation in the region over the course of the first century or so of settlement. The key to a mechanistic understanding of the differential persistence of cultural variants in the early Chesapeake lies in the interplay between selection and both direct and indirect-bias learning rules operating in the framework of horizontal transmission structures.

Thus the account would include descriptions of Darwinian learning rules that characterize modern humans in general, of learning rules that evolved via selection of cultural variation in an English context during the late medieval and early modern periods, and of selection processes operating on cultural variation in the Chesapeake. Models of cultural change during the period should suggest how these evolutionary mechanisms were responsible for local processes and the manner in which alterations in the trans-Atlantic economy and the character of the Chesapeake environment affected their operation.

Unfortunately all we have is a few guesses about Darwinian learning rules and no guesses at all about English-derived learning rules that the colonizers brought with them. As I have noted in earlier chapters, what is needed is more detailed specification of the algorithms used in learning rules. For the former, all I can do is point to the general suggestion made in the previous chapter that human indirect-bias rules would be likely to include resource acquisition rates or wealth as indicator variables because of the correlation between these factors and fitness in a wide variety of environmental and social contexts. Similar reasoning suggests that differences in rates of resource acquisition would be the effects by which individuals would evaluate alternative behaviors, given sufficient insight to link the effects to their behavioral causes. Such learning rules were not the only ones operating in the early Chesapeake (see below). However, they do appear to have been responsible for the initial fixation of the two key cultural variants introduced in the Chesapeake soon after initial colonization: tobacco cultivation and indentured servitude.

When the Virginia Colony was initially established, small quantities of tobacco were already being imported into England from the Spanish West Indies. In 1617, after ten years of experimentation with a variety of unsuccessful economic strategies, Virginians shipped their first cargo of West Indian-derived tobacco to England where it met a small but growing demand for medicinal and social consumption (Morgan 1975:90). The addictive character of nicotine, along with the fact that consumption initially took hold among elites, guaranteed the spread of smoking, via simple direct and indirect bias, throughout the English population and the growth of demand. The second key innovation was indentured servitude. In the early 17th century a quarter to a third of English families employed servants on the basis of a one-year contract in which room, board, and wages were exchanged for agricultural labor. Indentured servitude was a modification of this system that transformed it into a credit arrangement. Individuals received payment prior to their term of service in the form of transportation costs across the Atlantic. Transportation costs were covered by their prospective labor for a period of about five years after arrival in the colony. The initial transaction, which took place in England, was formalized in a contract that could be bought and sold in Virginia. Agreements like this were taking place by 1620 (Galenson 1981:6-12).

High prices for tobacco through the 1620's and a linear relationship between the size of a tobacco crop and the number of laborers tending it meant that servant-using tobacco planters had a high probability of becoming wealthy, often very quickly (Morgan 1975:109-111,134). Thus there existed the causal relationship between the indicator variable and the two secondary variants, tobacco and servants, necessary to push the combination toward fixation in a population characterized by wealth-based indirect bias rules. In addition, judging from the written testimony of contemporaries, individuals perceived the connection between tobacco, servants, and wealth, indicating direct bias rules favored the combination as well (Morgan 1975:110). As a result of biased transmission, growing tobacco with indentured labor for the Atlantic market became a nearly universal strategy in the Chesapeake within five years of its initial appearance.

A fortuitous effect of the initial acceptance of tobacco and servitude was the creation of an asymmetric transmission structure among individuals already resident in the colony (tobacco planters) and new immigrants (servants). Three conditions are necessary for the operation of selection under such transmission structures. First behavioral variation must be culturally transmitted from residents to new immigrants. Second, behavioral variation among residents must be linked to the number of immigrants they were able to teach. Finally, there must be a supply of individuals capable of sustaining immigration over a long period of time. All three conditions characterized the English experience in the 17th-century Chesapeake.

Consider first the supply of immigrants. The supply of immigrants to the Chesapeake was first a function of growth in the English population from which they were drawn. The 16th century witnessed a steady rise in English population. After 1600 growth began to slow and it ceased entirely at the middle of the 17th century. During the third quarter of the 17th century, population actually declined. It was not until the middle of the 18th century that growth resumed (Schofield 1983). Just how might these changes have affected immigrant flows? Changes in population growth rates behind these trends were largely driven by changes in fertility controlled by age at first marriage. In turn fertility changes were a response to changes in the environment, specifically resource availability (Schofield 1983). This finding matches nicely what might have been predicted on neo-Darwinian grounds. When environments deteriorate and offspring are costly, individuals who delay reproduction may be at a fitness advantage over those who incur costs of reproduction, only to have offspring die (Blurton Jones 1986). This suggests that the aggregate reproductive behavior of the population was determined by learning rules keyed on resource abundance. Immigration should be a viable part of long-term reproductive strategies in the context of declining assessments of resource availability that are reflected in declining marriage rates. Crude marriage rates declined over the first three quarters of the 17th century (Schofield 1983). Hence England offered a ready pool of immigrants during this period. That reproductive strategies and individuals' assessments of their reproductive prospects played an important role in controlling the flow of immigration is supported by the observation that, in the sample of immigrants for which we have the relevant data, the great majority were young adults about to begin their reproductive careers (Horn 1979:62)

The existence of the second condition for selection, the transmission of variation from residents to immigrants, was guaranteed by indirect bias rules favoring wealth. Given such rules, the five years of a servant's contract became a period during which established planters tended to serve as models for their servants. In other words, servants were more likely to learn cultural variants from planters than planters were from servants. The information imparted to servants during this period became the basis of the means they would employ to make a living in the Chesapeake, once their terms of service had expired. The third condition, the causal link between behavioral variation and immigration, arose from the fact that the acquisition of servants required scarce resources whose availability to individuals was a function of, among other things, the strategies they employed in making a living. Purchasing servants required cash and in the Chesapeake the only way in which to acquire cash was by growing tobacco.

To see how the selection process worked and how it favored the maintenance of both servitude and tobacco cultivation at high frequency over the seventeenth century, consider the relationships among cultural fitness values under horizontal transmission associated with growing or not growing tobacco and employing or not employing indentured servants. The cultural fitness of individuals who were not tobacco cultivators was low since they had essentially no means of acquiring servants and this important means of transmitting to others prescriptions for alternative means of making a living was not available to them. For the same reasons, the fitness of individuals who grew tobacco but opted for forms of labor other than indentured servants was similarly low. For example slaves were first imported into Virginia in 1619 (Morgan 1975:297) but slavery remained at low frequency throughout most of the century. Since the probability that slaves would eventually be free and themselves become tobacco planters was vanishingly small, the cultural fitness of those employing them was low as well. On the other hand, individuals who grew tobacco with indentured labor not only taught laborers to become servant-using tobacco planters, but also acquired the means to obtain more laborers.

This selection process helped guarantee that the colony's economy would be dominated by a single crop grown by servant labor, as long as the market for tobacco expanded and the supply of servants was not outstripped by the ever increasing demand. These conditions would obtain until the last two decades of the 17th century. Because they obtained for so long, roughly three quarters of the immigrants to the Chesapeake Region arrived as indentured servants (Horn 1979:51-54).

Because of the large proportion of immigrants who arrived as servants, the selection process had profound effects on other aspects of behavioral variation in the region for much of the century. Any cultural variants that enabled planters to introduce more servants into the planter population would increase in frequency under it. Selection therefore affected the distribution of variants controlling the manner in which planters managed their production operations and how they reinvested cash surpluses from tobacco production. Given the links between tobacco, cash, and servant acquisition, the system favored agricultural strategies that optimized tobacco productivity per unit cost. Optimization would extend to crop planting and harvesting techniques, work regimens, and provisioning strategies for servants. There were limits, however, since strategies that lessened the probability of servants surviving their indenture in sufficiently good physical condition to establish their own farms would be selected against. Any cultural instructions that caused planters to reinvest profits in ways that allowed them to import more indentured servants would be favored by selection. Thus planters who made capital-intensive investments in facilities and infrastructure, beyond what was necessary for immediate productive needs, were at a selective disadvantage.

The selective regime would also affect the content of learning rules. In the early Chesapeake we can expect the wealth-based learning rules, which immigrants brought with them, to have been overlain by culturally transmitted rules in which the indicator variable was a close correlate of fitness in the servant-based horizontal transmission system. Selection would favor the spread of indirect bias rules instructing individuals to learn preferentially from models who controlled large numbers of laborers and/or produced large tobacco crops. Individuals who learned preferentially from such models would be at a selective advantage since they would thereby increase their own chances of growing large crops and acquiring servants.

Two processes worked to lower the importance of the servant-based transmission system over time, placing important constraints on the trajectory of change. The first is based on the operation of wealth-based indirect bias rules, whether Chesapeake-derived or not. If teaching servants was a large component of fitness, its effects on the frequency of variants in the population as a whole was tempered by indirect bias rules. Cultural variants favored in transmission to servants would spread to the extent that servants were able to acquire indicator characteristics favored by indirect bias rules. In other words, the extent to which the kinds of traits outlined above spread throughout the population was a function of the probability that newly freed servants could themselves acquire wealth or servants or produce large amounts of tobacco. This probability was a reflection of the amount of economic opportunity. We can expect this probability to decline with the passage of time from initial settlement of a given area, along with the decline in local availability of land. A second factor has much the same effect. With the decrease in local availability of land, learning rules would likely cause newly freed servants to move to more recently settled areas where their chances for resource acquisition and fitness benefits accruing therefrom were higher.

As a result of both these processes, we can expect deterministic sorting of cultural variants in the servant-based transmission system to be important in the early period of settlement of local regions within the Chesapeake. Historical research on patterns of population growth and changing economic opportunity and emigration arising therefrom suggest that this period should last on the order of 30 to 40 years (Carr and Menard 1979). After this time, the differential persistence of cultural forms will be more exclusively determined by biased learning rules whose content is no longer being actively maintained by the cultural fitness advantages of servant labor. Variability in cultural instructions that affect wealth acquisition and retention in general will assume increasing importance.

The actual importance of this selection process is a subject for empirical investigation. Distinguishing between variants that were driven to high frequency by its operation and variants whose trajectories were governed by Darwinian learning rules will not be easy. As we saw in the previous chapter, two avenues are available. One is based on the contrastive dynamics of the two kinds of processes. The selection system would seem to be slower and involve temporal lags (see below). The other depends upon the development of contrasting expectations concerning the kinds of variation favored under the two regimens of deterministic sorting. Ideally this requires more detailed characterizations of learning rules themselves, characterizations that are unavailable. However, some general suggestions are possible.

Individuals using indirect bias rules will preferentially adopt variants that are correlated with higher rates of resource acquisition. This leaves considerable latitude in the manner in which resources once acquired are invested. One option is further investment in productive facilities and labor, which has the effect of further raising the rate of resource acquisition of planters. However, it is likely that a point is reached at which the payoff in terms of Darwinian fitness from further increments of such investment reaches an asymptote and begins to decline, relative to other investment patterns (Smith 1987). This occurs as a result of increases in opportunity costs -- that is the costs associated with foregoing investments in other pursuits like attracting mates or social allies. Such foregone opportunities are costly because individuals who pursue them increase their fitness relative to those who do not. The Darwinian rules that humans use in biased learning of alternative cultural variants specifying how resources are to be used are obscure (Harpending et al. 1987:143). However the foregoing reasoning suggests that such rules should impose a limit on the extent to which individuals reinvest resources in production. This expectation offers a possible contrast with the kinds of investment patterns that would be favored under the servant-based selection system, where the cultural fitness of ever increasing reinvestment in production, land and especially labor, would be unconstrained by opportunity costs. For example, extreme economies in architectural construction technologies, which were unique to the Chesapeake among English colonies in North America (Carson et al. 1981), would seem to fit the latter pattern. Separating out the causal mechanisms responsible in this and other cases is a topic for future investigation.

The foregoing suggestions concerning the mechanisms operating to shape the course of English settlement in the Chesapeake are woefully incomplete. However, they set the stage for a systematic description of the outcome of deterministic sorting in the context of the two sets of environmental factors stressed at the beginning of this chapter: local ecological variation and changes in the trans-Atlantic economy. There are two aspects of Chesapeake behavioral variation whose temporal patterning I want to address here: variation in rates of settlement spread and the differential persistence of house plans. In both cases the initial analytical tactics, derived from the last chapter, are the same. First I outline patterning in the values taken by adaptively salient environmental parameters and then examine measures of culturally conditioned behavioral variation. It turns out that alterations in cultural variant frequencies governing both rates of settlement spread and house layouts correspond with changes in environmental parameter values that implies the variation is functional.

The two topics are related. As we shall see in the next section, the gross patterning in the pace at which English settlement spread across the region is the result of the effects of physiographic constraints on the implementation of settlement strategies that evolved during the early decades of settlement. Examination of temporal patterning in rates of spread therefore promises to yield insights into settlement strategies, the timing of shifts in them, and the manner in which they were affected by local ecological variation. Analysis of the process of settlement spread also allows specification of the time limits within which the servant-based selection process would have been important in the region as a whole. This in turn paves the way for understanding the effects of perturbations in the world economy on strategies for the organization of staple and subsistence production on plantations toward the end of the first century of settlement, perturbations whose effects are manifest in variation in the spatial organization of houses.

5.3 Settlement Spread and Ecological Barriers

The arrival of Englishmen on the banks of the James River in 1607 marked the beginning of an ultimately successful invasion of the Chesapeake. The invasion metaphor can be turned in an analytical direction, which leads to models developed in an ecological context to describe the spread of populations of newly introduced plant and animal species in novel habitats. In this context, the pace of invasion over time is controlled proximately by population growth and movement. The latter are in turn ultimately linked to the fit between the invading species' phenotype and the environment. For most species, the potential for phenotypic change on the ecological time scales on which invasions occur is limited and variation in rates of growth and movement is largely a function of spatial variation in adaptively salient characteristics of the environment. Spread is more rapid in favorable environments than in unfavorable ones. Cultural transmission, however, introduces a second source of variation by making possible alterations in behavior that spread among members of the population as the invasion proceeds. The pace of invasion for social learners is therefore controlled not only by environmental variation as it is encountered by them, but also by changes in socially learned behavior that may occur along the way. A curve describing the extent of the area occupied by invaders over time will exhibit changes of slope not only when ecological barriers are crossed, but also when adaptive functional variation is introduced into the population and subsequently spreads as a result of deterministic sorting.

5.3.1 Physiographic Constraints

At a regional scale, the principle environmental constraints on settlement spread in the Chesapeake were the product of a physiographic dichotomy that was obvious to contemporaries from the beginning of the English invasion. The dichotomy was between the Coastal Plain or Tidewater and the Piedmont, the eastern edge of the Appalachians, to the west. John Smith's map of Virginia, drafted in 1608 and first published in 1612, detailed with surprising accuracy the dominant features of the Coastal Plain, Chesapeake Bay and the major rivers that drain into it. He correctly located the western edge of the plain and beyond it drew an expanse of mountains arrayed in an arc beginning at the head of the Bay and extending west and south (Morrison et al. 1983).

The Piedmont consists of highly weathered metamorphic rocks, formed when the east cost was tectonically active. The Coastal Plain, on the other hand, accumulated on a passive continental margin, as the Atlantic Ocean widened. It consists of a large wedge of unconsolidated sands, silts and clays, eroded out of the Appalachian highlands and accumulated on the eastward slope of the Piedmont over the past 130 million years. The boundary between the Piedmont and Coastal Plain, where their stratigraphic contact surfaces, is the Fall Line. The contact between the resistant rocks of the former and the soft, easily eroded sediments of the latter encourages the development of falls and rapids in the river valleys that cross it (Glaser 1968). Until deforestation and intensive plow agriculture greatly accelerated silting of the lower drainages over the past two centuries, the Fall Line was the head of upstream navigation (Vokes 1957, Brush 1986).

The Plain itself is dominated by the Chesapeake Bay, which divides it on a north-south axis and separating the eastern from the western shore. To the north, the Bay has its origin where the Susquehanna River, running southeast across the Piedmont, meets the Coastal Plain. On the western shore, the Plain widens to the south and is crossed by five major rivers, the Patuxent, Potomac, Rappahannock, York and James, all of which flow southeast, more or less parallel to one another. The eastern shore is traversed by smaller rivers, the Chester, Choptank, Nanticoke, Wicomico and Pocomoke, all running to the southwest. Elevation above sea level increases running east to west. The eastern shore is a largely featureless plain, while to the west the topography of the western shore trends to a rolling upland. The higher elevations of the western margin of the plain have lead to greater erosional downcutting, deeper valleys and correspondingly greater relief (Vokes 1957).

The physiographic features of the Coastal Plain are largely a result of repeated changes in sea level during the Pleistocene. Periodic rise and fall of the sea caused stream gradients throughout the Chesapeake drainage to flatten and then steepen. Alluvial terraces formed and were dissected. As a consequence of sea-level rise, broad expanses of water extend up the major river valleys fifty to seventy-five miles inland from the Bay edge of the western shore. Many of their first and second-order tributaries are therefore navigable, providing unimpeded access by boat to areas in the interior of the peninsulas separating the rivers. The resulting shoreline is highly indented and lengthy but is occasionally punctuated by relatively straight sections of shore where the major rivers and the Bay itself are actively eroding their own banks, cutting cliffs up to one hundred feet high. The Atlantic side of the Eastern Shore is characterized by a long line of barrier beaches and submerged sandy shoals, produced by wave action, behind which lie shallow lagoons (Vokes 1957).

Thus the physiography of the region to offer variable resistance to the inland progress of an invader. The great length of shore that fronts on navigable water made much of the Coastal Plain almost immediately accessible to settlement. At the Fall line the colonists would confront a real barrier to settlement spread, representing a quantum jump in difficulty of access to the Piedmont.

5.3.2 Measuring and Modelling Spread

Accurate data on the rate at which the English invasion of the Chesapeake proceeded during the Colonial Period, that is a time series describing the area of land under English occupation at some minimal density, are not available. However two flawed measures of the spatial extent of settlement over time can be had from the documentary record. The first is based on the number of counties established in Virginia and Maryland. The second is based on the number of Anglican Parishes established in Virginia. Since Maryland had no state-sponsored, established church, a parish-based measure is not available for it. Using administrative units as proxies for geographical space is dangerous. There was variation between individual counties and parishes in the threshold size and population density at which settlement in an area was formally recognized. Both parishes and counties established during the later eighteenth century tended to be larger than their predecessors. Correcting for this effect requires estimating county and parish sizes, a refinement that will not be attempted here since the focus of this analysis lies on the 17th century. The second problem is that new counties and especially parishes were formed as a result of population growth in long settled-areas and thus do not reflect geographic spread. This problem was dealt with by starting with the parish and county systems as they existed at the end of the Colonial Period and reassigning establishment dates to units if they contained within their boundaries earlier units to which administrative continuity could be traced. If there were several such units, I used the date of the earliest.

This procedure excludes 4 of the 60 counties established in Virginia up to 1770 and 4 of the 16 established in Maryland. The resulting county time series begins in 1634 when the Virginia General Assembly adopted the county administrative system (Robinson 1918). Coincidentally this is also the date of initial English settlement of Maryland and thus of the beginning of its county time series (Land 1981:Appendix C). Of the 133 parishes established in Virginia before 1770, 86 survived this winnowing (Cocke 1960, 1965, 1967). The parish time series begins with initial settlement in 1607. Patterning shared by both the measures is likely to be more a reflection of the real world than of the imperfect measurement device being used to portray it.

I computed the cumulative number of Virginia parishes and Virginia and Maryland in existence at the beginning of each decade, beginning in 1610. Values for years in which no administrative units were formed were linearly interpolated from values in adjacent years in which they were. To facilitate comparisons between the two series, the counts were normalized, that is reexpressed as a proportion of the total number of units that existed in 1770 (e.g.Mack 1985). Taking the square roots of these values converts them to a linear scale whose values represent geographic distance

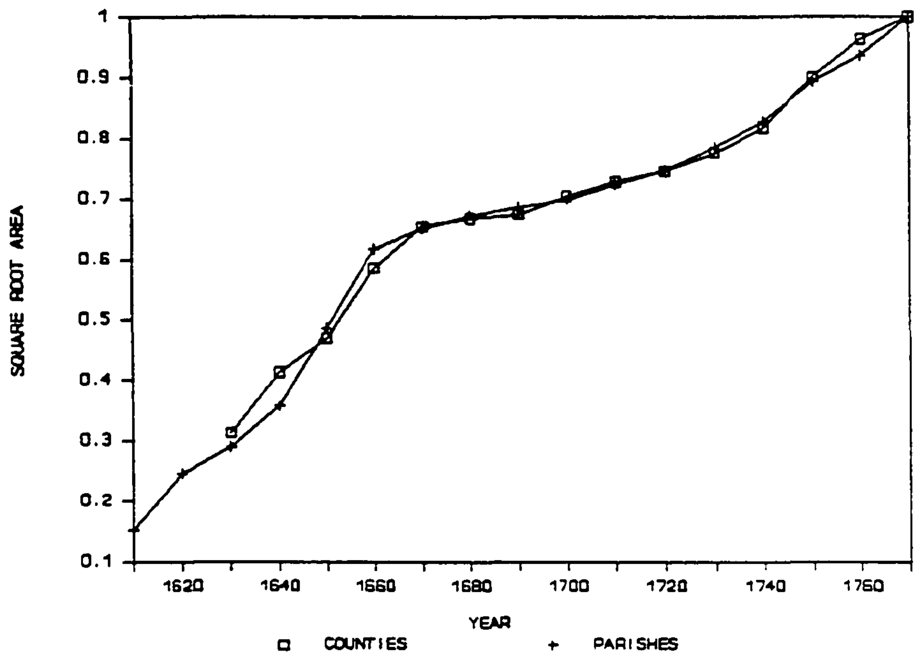


Figure 5.1 Settlement spread in the Chesapeake as measured by Virginia and Maryland counties (squares) and Virginia parishes (crosses).

covered by the invasion in a single dimension. The values are plotted against time in Figure 5.1. The overall shapes of the two curves derived from the parish and county data are similar. Each curve is comprised of three relatively straight segments, suggesting three major phases in the invasion in which rates of spread were more or less constant.

The curves reveal an initial phase of relatively rapid spread lasting to about 1660 or 1670. This is followed first by a phase of slower spread lasting until about 1730, and then by a resumption of more rapid spread beginning in 1730 and continuing to 1770. An examination of the location of counties formed during these three phases indicates that the latter do correlate with physiography. All counties formed during the first phase are located in the Coastal Plain. The few counties established during the second phase abutted the boundary between the Coastal Plain and the Piedmont. The third phase is dominated by the establishment of counties in the Piedmont, starting in 1721. The parish curve tells essentially the same story. The match between inflection in the curve and an ecological barrier suggests that the behavioral variation controlling settlement spread was functional, in the sense developed in the previous chapter.

The pattern of settlement spread may be understood proximately as the result of population growth rates and movement, that is typical distances at which new population members situate themselves in relation to members already present. These parameters are summaries of the strategies pursued by the invaders, averaged over the entire community. Population growth rates are indirect effects of those strategies, as well environmental perturbations in the larger English and Atlantic economy influencing the availability of immigrants. Movement, on the other hand, is a more direct reflection of settlement strategies pursued by invaders. Our understanding of the adaptive processes behind the invasion therefore is constrained by whether they worked through changes in growth or movement. An attempt to elucidate the ultimate causes and consequences of changing rates of spread requires that the latter be decomposed into these components. What is required is a model whose solution yields the required decomposition and permits an estimate of the movement component, given knowledge of rates of spread described above and population growth rates.

The required mathematics were worked out decades ago by Fisher and Skellam. Their models combine components that describe population growth on the one hand and movement on the other. Fisher's original treatment dealt with the spread of an advantageous gene along a single dimension. Skellam (1951) subsequently worked out a version of population growth in two dimensions and applied the results to the spread of oaks in post-Pleistocene England and the spread of muskrats in central Europe in the early part of this century. Two treatments are possible, depending upon whether population growth at the local level is assumed to be logistic or exponential. Under logistic growth, the rate at which individuals are added to the population is a function of local densities according to the recursion:

$$n' = n + rn(1\text{-}n/K) \tag{5.1}$$

Initially the number of individuals added to the local population in a time period is a function of the intrinsic rate of increase r. However, as local population levels approach the saturation level given by K, growth slows and population size stabilizes at K. Under exponential growth, individuals are simply added to the population at constant rate during each time period:

$$n' = n + rn \tag{5.2}$$

In archaeology, the treatment incorporating the logistic model has been used by Ammerman and Cavalli-Sforza (1973,1984) to examine the Neolithic spread of farming from Southwest Asia into Europe.

The second component of models of population spread is movement, that is a mathematical portrayal of the position of individuals who are added to the population, propagules, during each time period relative to those who are already present, parents.

A convenient way to think of movement is in terms of a "contact distribution", that is a probability distribution that describes the chance that a propagule will be situated a certain distance from its parent (Mollison 1977:283). Although a variety of distributions are possible, the Gaussian distribution is the one featured in the Fisher-Skellam treatments. For a population spreading on a two-dimensional plane, the position of a propagule relative to a parent is drawn from a bivariate Gaussian distribution with mean and covariance equal to 0 and with equal variances for the two coordinates. One can also think of this same process in terms of the distance a given propagule moves from the origin, with all directions considered equally likely. The mean-squared distance moved equals the variance along the coordinate axes. This picture treats movement as if it were a random walk. It does not imply that individuals ignore all information in navigating the environment, merely that at a population level, the distribution of movements approximates randomness.

I have described population growth and movement as discrete processes. However, the Fisher-Skellam model treats them as continuous, substituting differential equations for the population growth recursions and a deterministic, partial-differential equation, called the diffusion approximation, for the stochastic Gaussian contact process in discrete time. Couched in terms of population spread, Fisher's original insight into the continuous formulation implied that if the logistic growth parameter (r) and the mean-squared distance moved (s^2) were constant, then the leading edge of the spreading population would form a wave front whose velocity was given by

$$V = x_t/t = 2s\sqrt{r} \qquad (5.3)$$

Here x_t is the radius of the circular area occupied at time t (Williamson and Brown 1986, cf. Cavalli-Sforza and Ammerman 1984:80). Under exponential growth, no true wave front forms. However, given some threshold density for an area to be considered occupied, the velocity of spread of the area occupied will asymptotically equal 5.3 (Mollison 1977:294, Skellam 1951). This implies that whether population growth is logistic or exponential, the square root of the area occupied will increase linearly as a function of time, as long as the growth rate r and the mean-squared distance moved (s^2) remain the same. In other words, a plot of the square root of the area occupied during successive periods against time will be linear. The reason behind the similarity of results under logistic and exponential growth resides in geometry. The rate of spread is controlled for the most part by population growth at the edges of the occupied area where, under both models, growth is nearly exponential. As the invasion continues, the trajectory of population growth in longer occupied interior areas becomes increasingly irrelevant to the speed at which the invasion spreads across a region.

The model means that change in the slope of the line describing area occupied over time can in principle be decomposed into both the component processes of growth and movement if there are independent data on one of them. Given data on population spread and growth rates, the movement component can be inferred by rearranging 5.3:

$$s = V/\sqrt{r} \qquad (5.4)$$

For the Chesapeake, documents provide data on population numbers for the region as a whole. On the assumption that region-wide growth rates are proportional to intrinsic rates of increase at the edges of settlement, Equation 5.4 can be used to produce estimates of s, root mean-squared distance moved, during successive periods. Recall that of the two parameters, r and s, s is a more direct reflection of locally-derived settlement strategies.

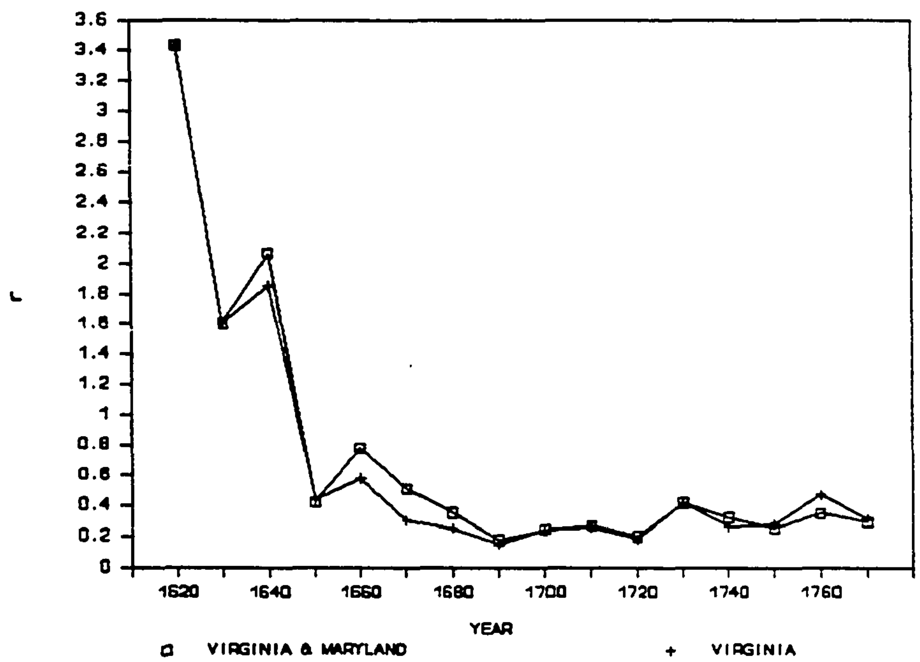


Figure 5.2 Growth rates by decade of taxable population of Virginia (crosses) and Maryland and Virginia (squares) from 1610 to 1770.

Contemporary census figures are available at sufficiently frequent intervals to make possible regular estimates of growth rates. In the great majority of instances, these counts are of "taxable" individuals. Over the period the definition of who was taxable changed, but essentially it included adult white males and adult blacks of both sexes, ostensibly the agriculturally productive members of society (Rutman and Rutman

1984b:25, Menard 1980:116). Numbers of taxables are reasonable for operationalizing the invasion model these figures approximate the number of individuals engaged in agricultural production. In order to estimate population growth rates, I collected estimates of taxable individuals at ten year intervals, beginning in 1610. Menard (1980:157-161) gives numbers of taxables for Virginia and Maryland for the period from 1630 to 1730. Total population figures for 1610 and 1620 are from Earle (1979) and taxables are derived from them using Morgan's total-to-taxable ratio for 1625 (1975:404). I estimated taxables for the period 1740 to 1770 by dividing total population figures (U.S. Bureau of the Census 1975:1168) by Menard's (1980:161) taxable-to-total ratio for 1720 and 1730.

Patterning in population growth rates over time is portrayed in Figure 5.2. Note that rates of population growth appear to have had a loose relationship with spread. Taxable population grew most rapidly during the first four decades of settlement, to about 1640, driven largely by immigration. There was a dip in the rate of increase during the 1620's. After an abrupt decline in the 1640's, caused by lowered immigration associated with the disruptions of the English Civil War, growth rates slowed continually from 1650 to about 1690. After 1690 population growth rates remained more or less unchanged until the 1720's when there was a slight increase to a level that was more or less maintained for the next fifty years.

I shall omit commentary on the complex mix of local population increase and immigration that lies behind these data. Instead, I want to use them to compute estimates of root mean-squared distance moved (s). I computed estimates of s for ten-

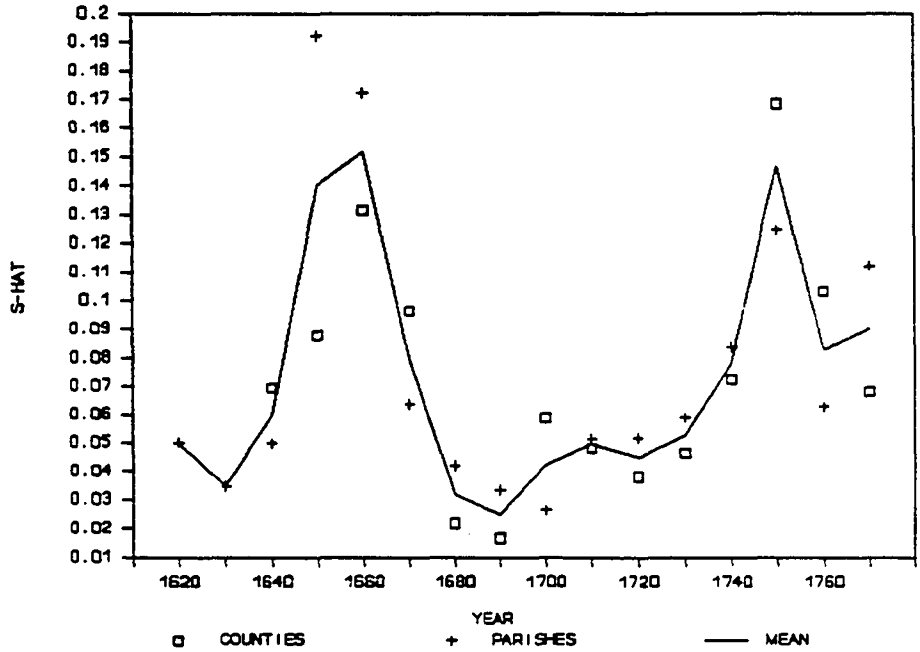


Figure 5.3 Decennial estimates of s for Virginia parishes (crosses) and Maryland and Virginia counties (squares), from Equation 5.4 and population growth rates for taxables. The line represents the mean of each pair of estimates.

year intervals, beginning with 1610-1620, using rates of spread based on the normalized Virginia parish and Maryland and Virginia county data and the growth rates for taxable population (Figure 5.3). The pairs of values of s derived from the parish and county series are similar to one another. The mean of each pair provides a simple summary of the pattern shared by them.

Some changes in the value of s are coincident with the invasion front's encounter with ecological barrier described earlier. Note the drop in the values of s during the 1660's as settlement approached fall line and the rise in value of s beginning in the

1730's when settlement of the Piedmont began in earnest. However, the relatively low values for distance moved that characterized the first few decades of settlement and the shift to the high values of the 1640's and 1650's are anomalous. No ecological barriers were crossed during this period. Hence this alteration represents the emergence of novel characteristics of settlement strategies. Just what aspects of settlement strategies were involved?

A possible answer to this question would point to an alteration in the organization of individual settlements that occurred during the 1620's. During the first two decades of settlement sites were widely scattered throughout the James River drainage, from the Fall Line to the Bay (Hatch 1957:33-34). The three sites from this period known from excavation exhibit two types of internal organization. Wolstenholme Town (44JC115,120), several miles downriver from Jamestown contains at least three households scattered around large storage and processing facilities (Noel Hume 1982). Excavations further upriver at Flowerdew Hundred (44PG65,72,62,86) have revealed a similar arrangement of storage and processing structures, lying inside a single fenced enclosure, with multiple houses adjacent to it (Deetz 1988). The Maine (44JC41), just outside Jamestown, is a cluster of at least two households that lacks the centralized storage and processing facilities (Outlaw 1978). By about 1625, both types of multiple-household clusters were disappearing from the settlement repertoire and were being replaced by settlements which contained only single households. The coincidence of this change with rise of the tobacco-servant based economy indicates the two were related. One aspect of the connection lay in the fact that individual households were able to acquire laborers and thereby create more individual householders through horizontal transmission. Before the advent of servitude and the cash crop, importation of immigrants required more complex forms of organization implied by the Wolstenholme and Flowerdew sites. A second aspect of the connection, leading to large distances between single household settlements, lay in the operation of the swidden cropping system that the English had learned from the Chesapeake's native inhabitants. The system minimized effort devoted to land clearance and maintenance of field fertility but in doing so vastly increased the amount of land required by a household practicing it (Earle 1975:29). This had the effect of increasing the costs in travel time and effort from house to field to be paid by individuals in clustered settlements comprised of multiple households.

The demise of both types of settlement comprised of clustered households might be expected to lead to higher values of s. However, as the foregoing description suggests, it is unlikely that it was responsible for the increase in the value of s observed for the 1640's. The best evidence for the timing of the shift away from clustered settlement comes from Wolstenholme, which was destroyed by native Americans in 1622. When the tract was reoccupied by the English later in the same decade, scattered single-household settlements were the means by which this was accomplished (Noel Hume 1982). Although the dating evidence there is less precise, abandonment of the Maine occurred during the 1620's (Outlaw 1978). Abandonment dates for the Flowerdew sites are considerably less secure, although there are indications that the enclosed area (PG 65) was in use well into the second quarter of the century. Thus the transition to dispersed, single-household settlements was under way during the 1620's, while the jump in the values of s does not occur for another two decades.

This suggests that the high values of s found in the 40's and 50's represents a shift in the frequency of some aspect of strategies among individuals who, for the most part, had already abandoned clustered settlement. Just which aspect may be ascertained by an examination of the settlement pattern that existed at the beginning of the period of lower s. Fortuitously, Augustine Hermann's map of the Chesapeake, completed in 1673 purports to show the locations of households. (Morrison et al. 1983). If the accuracy with which he placed individual plantations is questionable, the general pattern matches the results of recent archaeological survey and is likely a faithful reflection of reality (Smolek et al. 1984). Settlement was confined to lands fronting on navigable water, and with a few exceptions all the land on navigable water was settled, a pattern indicative of the adaptive importance of that feature. The exceptions support this inference since they are areas where the configuration of the coast made access from land to water difficult, the cliffs along stretches of the western shore of the bay above the Patuxent, or where off-shore features made approach by ships dangerous, the ocean side of the eastern shore with its shoals and barrier beaches.

The high values of s for the preceding period emerge as an artifact of near universal site location close to navigable water. This locational strategy, apparently widely disseminated by 1640, allowed those who pursued it to spread across the landscape without incurring the costs of developing, maintaining and using transportation infrastructure necessary for access from interior areas of the peninsulas to Atlantic markets, where the tobacco staple could be sold and the labor and tools to produce it procured. The result was a highly decentralized system for marketing tobacco lacking central places for collection and storage of the crop and characterized by common direct dealings between producers and ship captains or ship-board agents of English merchants (Carr 1974). This hypothesis implies that the relatively small values of s characteristic of the 20's and 30's are the result of locational tactics that resulted in settlement spread inland, away from the shores of the James River and its major navigable tributaries. Unfortunately, the sort of systematic archaeological survey data, accompanied by fine-grained chronological control, necessary to test this proposition do not exist. The archaeological data that are available merely attest to the general importance of near-water site location (Smolek et al. 1984).

The puzzle is why the large increases in s do not occur until well after the tobacco-servant combination was in place. One answer is that this is the expectable consequence of the mechanism by which the strategy was fixed. Recall from Chapter 3 how under deterministic sorting, trajectories are logistic, that is rates of change are slow initially followed by rapid increase. To some extent the delay may be due to this effect. However, it also might suggest that the mechanism at work here was the selection process outlined earlier, and not simply biased learning rules. The delay is suggestive of the selection process because the dissemination of the variants favored by it depended on servants becoming planters who acquired the valued indicator characteristic, wealth. This process presumably took several years. The operation of biased learning rules based solely on rates of resource acquisition did not depend on the former factor.

The changing settlement strategies implied by s exemplify the failure of the 17th-century Chesapeake to live up to the characterization of frontier settlement pattern implied by the colonization gradient of the frontier school (cf. Lewis 1984). During the 17th century, there was no dendritic network of settlement connecting frontier towns to successively smaller central places. In fact there were no central places at all, with the exception of the administrative capitals of the two colonies at Jamestown and St. Mary's City. Nor was there any decline in complexity of the settlement system along a gradient from more to less recently occupied areas. The entirely decentralized settlement pattern was the predictable consequence of deterministic sorting of site location preferences in the context of the tobacco-servant economy and Chesapeake's physiography. The complexly indented shoreline offered sufficient land on navigable water that these strategies would be adaptive for decades.

After 1670 the value of s plummeted and remained low for the following sixty years. Low values characteristic of this period are an indication that settlement was spreading to the interior areas of the Coastal Plain's peninsulas, leading to increased population densities throughout the region. The shift can be seen as a simple consequence, in the context of rapidly disappearing river frontage, of the operation of preferences for site locations close to navigable water that were fixed during the previous period. The interior areas of the peninsulas were favored over the Piedmont because the former offered more land closer to navigable water. As settlement spread away from the rivers, inland transportation infrastructure slowly developed. Initial investments and maintenance costs for roads, carts, containers, traction animals and labor no longer placed a subset of newly introduced members of the population at a disadvantage relative to other new immigrants because all had to make them. Spread away from deep water and increased numbers of individuals opened niches for local middlemen to facilitate the collection and transport of tobacco from interior areas and the supply of imported goods to them. In some areas small central places sprang up at strategic intersections of inland transportation routes with the riverine system, containing warehouses and stores of local merchants dealing with both smaller neighborhood middlemen and tobacco producers (eg. Rutman and Rutman 1984a:204-233). Thus it was only at the beginning of the 18th century that the region began to witness the development of a settlement pattern that resembled the generalizations of the frontier model.

It was not until the 1730's that distance moved increased substantially. It remained high for the rest of the Colonial Period as settlement spread into the Piedmont and Ridge and Valley. This development is presumably an indication that population levels in the Coastal Plain had reached saturation levels, that at least under current agricultural regimens the region was ecologically full.

The implications of shifting rates of settlement spread for the timing of the demise of the tobacco-servant selective regime are straight-forward. The 1640's and 50's, when values of s were high, are the decades during which most of the Coastal Plain, outside the James River drainage, was initially settled. As we have seen, economic opportunity for newly freed servants had dropped to very low levels roughly 40 years after initial settlement of an area. This implies that on average for the Chesapeake region as a whole, the importance of the selection regime would have dwindled by the 1680's and 90's. In other words, by the last two decades of the century, deterministic sorting of cultural forms should be largely caused by biased learning rules alone. This point is important for understanding the effects of perturbations in the Atlantic economy on the Chesapeake. It implies that by the end of the century, deterministic change through out most of the region would be caused by the same set of mechanisms. The qualification is necessary since limited settlement spread continued into previously unoccupied areas at the western edge of the Coastal Plain from the 1670's onwards and in these regions the effects of selection in the servant-based transmission system would still be important. However, for the most part, we can expect to see more-or-less synchronous and similar responses throughout the region to selective pressure generated by the Atlantic economy.

In this section I have tried to show how the settlement history of the 17th-century Chesapeake was the outgrowth of both local ecological conditions, changing settlement strategies pursued by the invading population, and the local processes responsible for those strategies. Together they produced homogeneous settlement strategies with limited clinal variation in time and space of the sort described by the frontier school. In the next section I stress the other side of the coin: the importance of environmental parameters whose values were set by the larger economic system on which the tobacco-based adaptation of the Chesapeake depended.

5.4 House Plans and the Atlantic Economy

This section begins with an examination of the kinds of selective pressures generated by changes in the Atlantic economy toward the end of the 17th century. I then turn to a systematic description of the differential persistence of house plans across the century. Here again the goal is to examine temporal patterns in culturally conditioned phenomena for correspondence with environmental changes indicative of functional variation.

5.4.1 Global Economic Constraints

Changes in the Atlantic economy in the late 17th century affected the mainstays of the Chesapeake economy: the demand for tobacco and the availability of labor with which to grow it. Consider shifts in the availability of labor. Earlier I argued that the supply of English immigrants to the Chesapeake was first of all a function of prospective immigrants' assessments of reproductive chances at home. Declining marriage rates indicate these were dropping for most of the century, rasing the probability that individuals would emigrate. However, crude marriage rate rose briefly around 1650 then declined again until 1670 when they entered an upward trend that would continue well into the next century (Schofield 1983:278). Rates of emigration from England followed a roughly reciprocal course, decreasing when marriage rates increased. After increasing for decades, the total number of English migrants to the Americas declined during the 1660's and trended downward for the remainder of the century. Not only were there fewer individuals leaving England, but fewer of those that left went to the Chesapeake. Through the 1670's, a steadily increasing proportion of English migrants ended up in the Chesapeake. However, the last two decades of the century witnessed a decline, as the Chesapeake suffered from competition for immigrants from colonies in Pennsylvania and the Carolinas that were opened to settlement about 1680 (Main 1982:10).

Alterations in the availability of English migrants were felt immediately in the Chesapeake. Their effects are evident in declines in the mean number of laborers per household as recorded in probate inventories. Complete time series are available for the lower western shore of Maryland and for York County, Virginia. In Maryland the mean number of laborers per estate dropped from roughly 2.0 to 1.5 from the 1660's to c. 1680. York County witnessed an even more dramatic decline from about 2.5 to 1.2 during the same period. As the supply of servants dwindled, prices for indentured servants increased during this period, after several decades of stability (Menard 1977). These changes represent large declines in the mean value of a variable that itself was an indicator variable or was a close correlate of one.

Alternative sources of labor supply had been available, most notably African slaves. Slaves had been part of the labor force from 1619. The low cultural fitness of slave ownership in the servant-based selection process guaranteed that the practice would remain at low but regionally variable frequency. There are indications that at mid-century the frequency of slaves in a given region, as a proportion of the total unfree labor force, was a function of the region's date of settlement. For example, in 1660 roughly 30% of the labor force of York was comprised of slaves (Menard 1977:368), while in the same decade in Westmoreland County, Virginia the frequency was 8% (Westmoreland II, IV). The York area was first settled in the 1620's, 30 years before Westmoreland. This is the pattern predicted by the hypothesis suggested earlier that the servant selection mechanism would be replaced by indirect bias rules as the major cause of deterministic sorting with time since initial settlement. Longer settled regions, where the selection mechanism was weaker, had higher frequencies of slaves.

The initial settlement of the majority of the Coastal Plain by the 1640's and 1650's meant that importance of the selection mechanism was small by the last two decades of the century throughout most of the region. As a result, slave ownership was no longer being actively selected against. Due to the importance of (complex) indirect bias and the decline in economic opportunity, planters who continued to purchase servants were no longer contributing the prescription at disproportionate rates to the population at large. On the other hand, they were able to acquire fewer laborers and were paying higher prices for them. Planters who purchased slaves were no longer at a cultural fitness disadvantage and were able to acquire more laborers than those who purchased servants. In the tobacco economy, rates of wealth accumulation directly scaled with labor force size. Servant purchasers would suffer declines relative to slave purchasers. Thus there existed the causal connection between secondary variant, the use of servant or slave labor, and indicator trait, rates of resource acquisition or wealth, necessary to push slave owning to high frequency in the population. The frequency of slave ownership increased and the Chesapeake labor force became predominantly black. Although there was some regional variation correlated with date of initial settlement, the transition was concentrated in the late 1680's and the 1690's (Menard 1977:368-369, Earle 1975:46).

The last two decades of the century also saw changes in the market for tobacco, arising from a variety of sources. Throughout the century, tobacco prices declined by an over an order of magnitude although there was a great deal of year-to-year stochastic fluctuation (Menard 1980, Wetherill 1984). Although the English market for the drug expanded steadily during the early decades of settlement, the number of individuals growing it in the Chesapeake grew even more rapidly. Hence the price decreases of the 1620's and 30's were the steepest when Chesapeake growth rates were highest (Figure 5.2). Prices continued to decline into the 1680's when they bottomed out and remained at low levels into the second decade of the next century. The trough was due to the fact that during the 1680's the English market was saturated, demand stabilized, and total production leveled off. However, the number of producers continued to increase. Demand for Chesapeake tobacco remained stagnant until the 1720's when English merchants gained access to new markets in France and Holland (Main 1982:221-23). It was only then that tobacco prices began sustained increases.

A final perturbation in the Atlantic market that affected Chesapeake planters late in the century was war between France and England that flared on and off from 1689 to 1713 (Main 1982:21-23). Shipping costs increased dramatically during this period, placing further economic burdens on Chesapeake planters (Menard 1977:147). In some years, the fleet that transported tobacco to England failed appear on the Chesapeake's shores in sufficient numbers to accommodate the entire tobacco crop. War also foreclosed access to European markets that might have consumed the Chesapeake's excess supply of tobacco (Menard 1980:139).

The last two decades of the 17th century witnessed important changes in Atlantic market conditions that directly affected tobacco planters in the Chesapeake. The changes first of all produced high levels of economic stress, due to low tobacco prices, and higher labor prices. This at a time when indirect-bias rules keyed on wealth acquisition were becoming the dominant evolutionary force in the region. Changes in labor availability brought into action forces that caused the shift from a labor force dominated by white indentured servants to one dominated by black slaves. Both economic stress and the altered racial composition of the laboring population constituted environmental conditions that, for reasons to be detailed later, should have brought into existence forces affecting the frequency of variable means of organizing production and work on individual plantations. A key feature of these means was the manner in which individuals partitioned and used the spaces of their houses for work and productive activities. In the next section, I turn to an examination of temporal patterns in the differential persistence of house plans to suggest that the last two decades of the century were in fact a period of deterministic sorting.

5.4.2 Measuring Plan Forms

As a first step we require tools with which to measure the differential persistence of house plans across the time period under consideration. Students of English vernacular architecture have developed a variety of terms for describing variation in plans of medieval and post-medieval houses, often calling the results classifications. These systems are unsatisfactory for our purposes for two reasons. First, because they were developed for use with extant structures, they are based on details of interior partitioning that even in the best of circumstances are ambiguously represented in the archaeological record. Descriptions of the record cast in such terms are thus often more a reflection of uncontrolled inferences on the part of the describers concerning the configuration of missing elements than they are of empirical variability. The second problem resides in the fact that the categories, or "classes", constructed with them lack explicit definitions. The types are defined by illustrating "typical" specimens, not by offering a list of necessary and sufficient conditions for class membership (e.g. Eden 1969, Upton 1980:48,50, see below). Symptomatic of the problem is the embarrassment of "hybrids", specimens which do not exactly resemble any of the specimens that happen to be illustrated as examples of the types or combine features of different examples. Without systematic definitions, not only is it is unclear which aspects of variation are being measured when a particular house is assigned to a class, but it is also likely that different aspects of variation are measured in different applications of the classification.

What is required is a more systematic approach, based on explicitly defined dimensions of variation. Four dimensions of variation are important here, each of them an aspect of variability in the layout of the rectangular core of a structure. The first is a measure of size that is sensitive to the number of major front-to-back partitions in the core. Size is measured in terms of numbers of unit spaces defined as follows. Where the physical remains of axial partitions exist in the record (e.g. fireplaces, postholes), each partitioned space they separate is counted as a unit. There is no minimum on the length of a unit defined in terms of the archaeological remains of partitions. However, there is a maximum limit, arbitrarily set at 1.33 times the structure's width. An unpartitioned space less than 1.33w in length is 1 unit long. A space whose length lies from 1.33w up to 2.66w is 2 units long. A space from 2.66w up to 4w is 3 units long, and so forth. The number of units in the core of a structure is intended to capture the minimum number of major axial divisions that constrained movement within it.

The other two dimensions of variation are less complex. For houses with a single principle entry four modes are recognized: direct entry into an end unit (E), direct entry

Table 4.3 Classification of house plans to c. 1720.

SITE		DATE	ENTRY	FP	NUNITS	UNITS	REFERENCES
SITE D	44JC115	1620	.	.	2	.	Noel Hume 1982
SITE C/H	44JC115	1620	.	.	2	.	Noel Hume 1982
SITE C/A	44JC115	1620	.	.	2	.	Noel Hume 1982
SITE C/D	44JC115	1620	.	.	4	.	Noel Hume 1982
SITE H	44JC120	1620	.	E	3	.	Noel Hume 1982
ENCLOSED AREA	44PG65	1618	E	E	2	UU	Carson et al. 1981
OVEN SITE	44PG82	1618	E	E	1	U	Kiser, pers. com.
MAINE S1	44JC41	1618	.	C	3	HUH	Carson et al. 1981
MAINE S4	44JC41	1618	.	C	3	HUH	Carson et al. 1981
LITTLETOWN 1	44JC35	1620	.	.	2	HU	Carson et al. 1981, Kelso 1984
KINGSMILL TENEMENT 2	44JC39	1630	.	.	2	.	Carson et al. 1981, Kelso 1984
LITTLETOWN 2	44JC35	1630	.	.	2	.	Carson et al. 1981, Kelso 1984
SGRAFFITO	44PG72	1620	.	.	3	.	Kiser, pers. com.
SITE B	44JC113	1630	E	E	2	.	Noel Hume 1982
PASBEHAY TENEMENT	44JC42	1635	E	E	2	HU	Carson et al. 1981
BOLDRUP	44NN5	1630	E	E	2	.	Luccketti, pers.com.
EPPS ISLAND	44CC7	1630	.	E	2	UU	Luccketti, pers.com.
RIVER CREEK 1	44YO67	1636	E	E	2	.	Carson et al. 1981
COUNTRY'S HOUSE	18ST1-13	1635	ML	CE	3	HUU	Stone 1982, Miller 1986
SITE A/C2	44JC116	1630	E	CE	3	HUH	Noel Hume 1982
MATTHEWS MANOR 1	44NN44	1630	M	C	3	HUU	Noel Hume 1966
MATTHEWS MANOR 2	44NN44	1630	E	C	4	HUUU	Carson et al. 1981
HAMPTON 1	44HT55	1630	E	C	2	UU	Edwards, pers.comm.
ST. JOHN'S	18ST1-23	1638	L	C	3	HUU	Stone 1982, Carson et al. 1981
STONE HOUSE	44PG64	1620	.	C	2	HU	Carson et al. 1981
BENNET FARM	44YO68	1650	E	E	2	.	Carson et al. 1981
COMPTON	18CV279	1650	E	E	1	U	Edwards, pers. comm.
BACON'S CASTLE	44SY117	1655	E	E	2	UU	Upton 1980
JOHN WASHINGTON	44WM204	1656	E	E	2	UU	Carson et al. 1981
TOWN POINT	44SK8	1650	M	CE	3	UUU	Opperman, pers.comm.
PETTUS	44JC33	1641	L	C	2	UU	Carson et al. 1981, Kelso 1984
MATTHEWS MANOR 3	44NN44	1650	L	C	2	UU	Carson et al. 1981
DRUMMOND	44JC43	1648	L	C	2	UU	Carson et al. 1981
MIDDLE PLANTATION 1	18AN46	1670	.	.	2	.	Carson et al. 1981
RIVER CREEK 2	44YO67	1660	E	E	2	.	Carson et al. 1981
UTOPIA	44JC32	1660	E	E	2	UU	Carson et al. 1981, Kelso 1984
VAN SWERINGEN	18ST1-19	1677	ML	CE	3	UUU	King and Miller 1988
HALLOWES	44WM6	1670	L	C	3	HUU	Buchanan and Heite 1971
SMITH'S	18ST1	1666	L	C	2	HU	Miller 1986
CLIFTS 1	44WM33	1670	ME	C	3	HUH	Neiman 1980a
HOLLY HILL	AA-246	1698	E	E	2	UU	Carson et al. 1981
KING'S REACH	18CV83	1690	E	E	2	UU	Pogue 1988
MIDDLE PLANTATION 2	18AN46	1710	.	.	2	UU	Carson et al. 1981
CEDAR PARK	AA-141	1702	E	E	2	UU	Carson et al. 1981
SARUM	CH-15	1717	E	E	2	UU	Stone 1982
FLOWERDEW TOWN	44PG66	1700	E	E	2	UU	Carson et al. 1981
OCEAN HALL	SM-111	1720	E	E	2	UU	Stone 1982
LITTLETOWN	44JC--	1700	E	E	2	UU	Kelso 1984
WOODWARD-JONES	44SK147	1716	E	E	1	U	Carson, pers. comm.
SOTTERLY	SM-7	1710	E	E	2	UU	Stone 1982
SWEET HALL	50-67	1720	E	E	2	UU	Upton 1980
MOYSONEC	44NK32	1700	E	E	2	.	Carson et al. 1981
JOHN HICKS	18ST1-22	1720	E	E	2	UU	Stone 1982

into a middle unit (M), entry into a lobby (L), and unknown (U). Three additional modes are necessary to accommodate plans that had multiple entries: Lobby and end entry (LE), lobby and middle-room entry (LM), and middle and end room entry (ME). There are four modes describing fireplace placement: end (E), interior (I), both end and interior (EI), and unknown (U).

Finally, for a few sites where the archaeological remains of axial partitions are particularly complete, where no undivided space is greater than 1.33w long, and for standing structures, it is possible to refine the unit measure further by distinguishing full (U) and half (H) units, where U>.66w and H<.66w. Houses can then be described as ordered n-tuples of U's and H's, with mirror image n-tuples assigned to the same class (e.g. HU=UH). This makes possible a more precise characterization of interior partitioning.

Measures of plan variability are derived from this scheme in two ways. The first is a paradigmatic classification (Dunnell 1971) based on all possible combination of modes from the first three dimensions of variation: number of units, kinds of entry and fireplace placement. Classes in this system can be referred to using the letter designations given each mode above. Thus a 2/E/E plan is 2 units long, has direct entry into an end room and end fireplace(s). Variability along the dimension of ordered n-tuples of full and half units is considered independently of the other dimensions, given the small number of structures to which it can be applied.

5.4.3 Temporal Patterning

Having developed a means of measuring variability, we require phenomena to measure, that is a sample of house plans spanning the period of interest from initial settlement to c.1720. Given the lack of published data, it is difficult to assemble a complete and well-reported group of house plans known from excavation and from architectural field work. The sample I have managed to assemble is just that: the sample I have managed to assemble. It is drawn from the grey literature and from unpublished copies of site plans furnished by excavators. Table 5.1 gives a complete list of the sites included. The archaeological sites represented there comprise the great majority of those excavated. Initial occupation dates, based on artifacts and documentary evidence, are those supplied by the excavators. Most of the data for the early eighteenth century are from extant structures. Recent dendrochronological work has for the first time provided systematic evidence for their dates of construction. These prove much later than dates traditionally offered by architectural historians and antiquarians (Heikkenen and Edwards 1983). Hence I have only included extant structures for which there is dendrochronological evidence.

Table 4.4 Number of house plans of different paradigmatic types known from excavation in the Chesapeake.

ENTRY:	E	.	.	E	L	.	E	.	.	L	M	ME	E	M	ML	.	.	E
FP:	E	.	C	C	C	E	E	.	C	C	C	C	CE	CE	CE	E	.	C
UNITS:	1	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4
1700-20	1	1					9											
1680-99							2											
1660-79		1			1		2			1		1			1			
1640-59					3		3							1				
1620-39		3	1	1		1	4	1		1	1		1		1			1
1607-19	1	3					1		2							1	1	

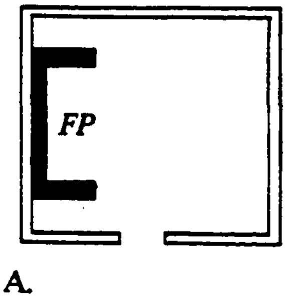
Tables 5.2 and 5.3 show the temporal distribution of class members to c. 1720. Plans are grouped into 20-year periods. The classifications reveal similar patterning. There is a marked drop in diversity or heterogeneity over time, much of it apparently concentrated c. 1680. Consider the paradigmatic classification first. The overall trend is toward lower diversity over time. Although sample sizes are small, there appear to be two periods of sorting. The first occurs at the end of the first period, that is c. 1620. This period is dominated by plan types characterized by unknown fireplace and entry locations. The uniqueness of these early plan types is to a large extent an artifact of the expedient and hence ephemeral character of the architectural technologies employed to construct them (Carson et al. 1981, Stone 1982:250-256). The second period of sorting occurs after c. 1680. After that time plans having 3 units, lobby entries, and central fireplaces, all of which were employed in various combinations from 1620 to 1680, disappear from the repertoire.

The only types built during the last two periods were 2 or 1 units, with direct entry and end chimneys (Figure 5.4). The patterning captured by ordered n-tuples of full and half units is similar. Expectedly, since plans whose unit sizes are unknown are excluded entirely from this analysis, the first period appears less unique. However, there is the same overall decline in diversity, with an apparent

Table 4.5 Number of house plans of various combinations of unit sizes known from excavation in the Chesapeake.

	.	HU	HUH	HUU	HUUU	U	UU	UUU	TOTAL
1700-20	1					1	9		11
1680-99							2		2
1660-79	2	1	1	1			1	1	7
1640-59	1					1	5	1	8
1620-39	6	3	1	3	1		2		16
1607-19	5		2			1	1		9

punctuation occurring after 1680. After that point, plans employing various combinations of full and half units disappear, leaving only houses of 1 and 2 full units.



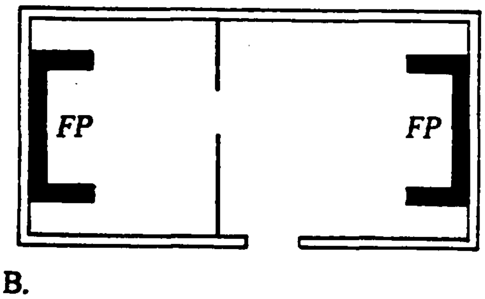


Figure 5.4 Examples of plan types in use in the early-18th century. A: U, 1/E/E. B: UU, 2/E/E.

Given the fact that population size was growing rapidly during this period largely from immigration, it is unlikely the decline in heterogeneity was due to drift in the absence of innovation. Rather, the patterning appears to be the result of a process of deterministic sorting. The limited number of structures in the sample makes it difficult to measure the extent to which deterministic sorting affected house-plan variation from 1620 to 1680. However, the changes evident after 1680 are sufficiently dramatic to be detectable despite small sample size. The correspondence of this period of sorting with the changes in the Atlantic economy outlined earlier is further evidence that a functional explanation is in order.

Two hypotheses have been proposed. With varying degrees of explicitness, they invoke two different sets of learning rules to link archaeologically documented variation in house plans to different aspects of historically documented economic change. The two hypotheses converge on the general character of the behavioral variation that is inferred to have been sorted in concert with variant plan forms. In both cases the hypothesized behavioral changes involve alterations in the way in which planters interacted with their laborers in a day-to-day basis. One hypothesis sees shifts in form-behavior combinations as an outcome of the changing social positions of laborers and planters relative to one another. The other attributes causal significance to economic stress. In the following sections I review these arguments and the mechanisms for deterministic sorting upon which they are based.

5.4.4 Previous Research

Architectural historians have played a seminal role in studying the plan changes documented above and in formulating a social interpretation of them. Initially their work was based on two components, neither of them involving evidence from excavation. The first was an appreciation of the architectural repertoire that 17th-century English immigrants to the Chesapeake brought with them, based on a large and growing literature on architectural variation in extant English farmhouses constructed during the 16th and 17th centuries (e.g. Barley 1961, Smith 1970, Mercer 1975). The second was a parallel increase in understanding of the character of architectural variation in extant houses in Virginia and Maryland (Carson 1974, Upton 1980).

The English vernacular architecture literature has not only offered evidence, but dictated the terms in which that evidence is cast. Variation is understood in terms of three-unit plans, with smaller houses seen as versions of the latter, built by individuals not wealthy enough to afford the full three units (e.g. Smith 1980:8). Three "types" of three-unit plans are distinguished on the basis of fireplace location and the kind of entry ([Mercer 1975, Smith 1980] Figure 5.5). The two entries recognized are the cross passage, a passage running between two doors placed opposite one another in the side walls, and the lobby entry described above. There are two cross-passage types. In the first the passage is separated from the middle room by a fireplace that heats the latter and the end room on the other side of the passage, the "lower room", is heated (3/E/EC in the classification offered above, see Figure 5.5A). Here the fireplace backs onto the cross passage. In the other, the fireplace heating the middle room is located on the end of the middle room away from the passage (Figure 5.5B). Here the lower room on the other side of the passage is not heated, but the room on the opposite end typically is (3/M/C or 3/E/C in the classification above). The third type has a lobby entry next to the side of a central stack heating the two rooms on either side of it, with the third room unheated (3/L/C, Figure 5.5C).

English work not only provides a formal description of three-unit houses, but also a parallel set of conventions for understanding use of the three rooms. In the two cross-passage plans, the room farthest from the passage is the chamber or parlor, conceived as

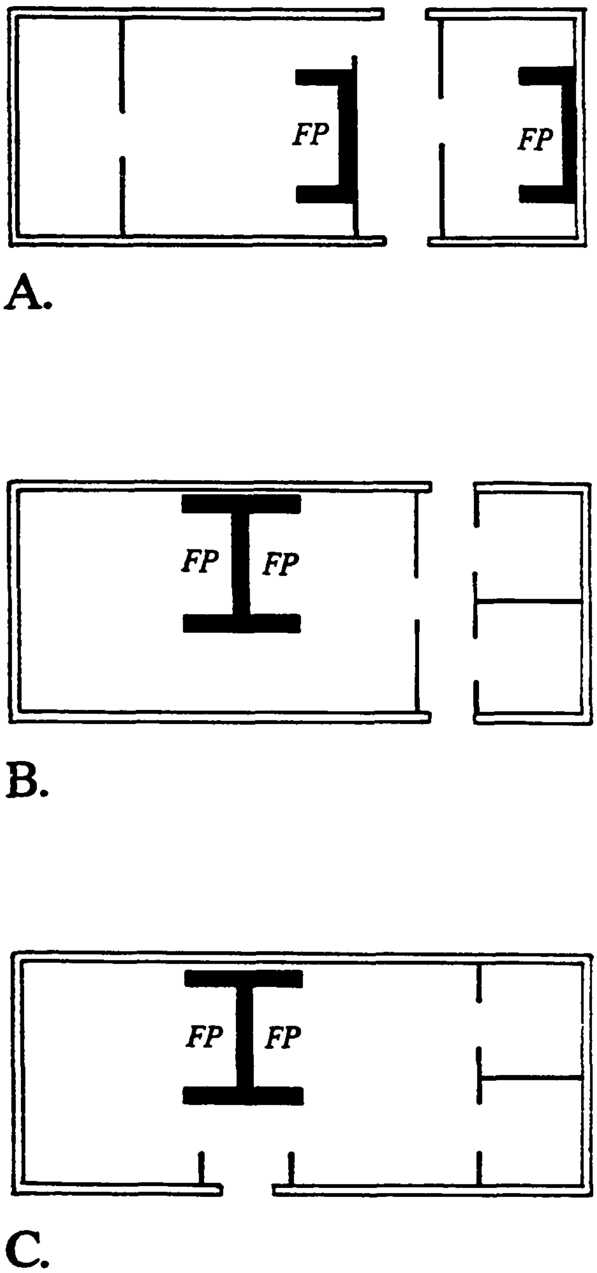


Figure 5.5 Three 3-unit house plans representative of the "types" recognized in literature on English vernacular architecture. A: Cross passage with fireplace backing onto passage; B: Cross passage with fireplace away from passage; C: Lobby entry.

either a sleeping space or a more frequently used family living area, depending upon the absence or presence of a fireplace. The middle room is the hall, a general-purpose living area. The room below the passage is considered a service room. Where the service room below the passage was heated, it is thought to have been a kitchen. When it was unheated, it is understood as a place for food processing and storage that did not require a fireplace, while the hall was more of a kitchen. In the lobby entry house, the single room on one side of the stack is the chamber or parlor, while the two rooms on the other side are the heated hall and unheated service room (Mercer 1975:58). Evidence for these normative ascriptions of use for the three rooms come from contemporary documents, in particular probate inventories (Barley 1961, see below.).

Traditionally, variation in plan forms has been understood in terms of the highland-lowland geographical division that has structured British prehistory for most of this century (Fox 1932). England is thought to be divided into two geographical zones, separated by a line running from Torquay in the south, through Bristol, to the Tees, south of Newcastle, in the north. To the east of the line, the lowlands are an economically prosperous and culturally progressive area, while the highlands to the west are economically poorer and culturally receptive (Barley 1961:4). The three plans have distinctive regional distributions that parallel the division in a general way. The eastern lowland zone, and especially the southeast, is dominated by lobby entry, while the highland zone is characterized by the cross passage with fireplace backing onto it. Between them is a zone in which the cross passage with fireplace away from the stack -- a "transitional" form -- is popular (P. Smith 1980).

The geographical correlation is still stressed in much of the literature, where its explanatory value in a evolutionary context might be glossed in terms of the flow or diffusion, via migration or indirect transmission, of stylistic variants from east to west. However, more recently a competing interpretation has emerged that is based on the premise that the variants are functional. That the premise is correct is suggested by the fact that both the "conservative" cross-passage plans can be found in the southeast during the 16th century, but that the lobby-entry plan had become the dominant form in the region within 50 years of its introduction, c. 1550 (Barley 1961:68-69). Eric Mercer has been the leading proponent of this approach and, in particular, the hypothesis that regional differences in the frequency of the three plans are a function of the character of social relationships between farmhouse owners and their laborers. While Mercer's exposition is synoptic, the argument is that the plans can be ordered in terms of the amount of physical separation they afford between family and laborers and that the order is based on siting of the parlor relative to the entry and the presence of heat in the latter. At the high end of the scale, the lobby entry allowed family members separate access to a heated, and therefore frequently used, parlor, without their having to traverse the hall-kitchen and service rooms filled with servants (Mercer 1975:61). At the other end lies the cross-passage plan with fireplace backing onto the passage, where access to the parlor is through the hall and the parlor is unheated, small, and therefore used for little more than sleeping. The cross-passage plan with fireplace away from the passage is intermediate on this scale since access to the parlor is though the hall-kitchen, but the parlor is heated (1975:57-58). Under Mercer's hypothesis, the spatial distribution of plans was caused by geographically clinal variation in social stratification between laborers and their employers. In the southeast, where there were many wage laborers, the social gap between the two groups was greatest. In the highland zone, laborers tended to be "farmers' sons waiting to take over their father's lands and likely to marry their master's daughters" and the differences were minimal (1975:61).

Mercer's hypothesis is problematic for many reasons. Not the least of them is the fact, alluded to in our earlier discussion of classifications, that the entire facade rests upon a flawed measurement device. This is particularly bothersome in Mercer's case because his explanation of variation in plans is based on dimensions of variation -- parlor siting and heating -- that do not figure in grouping houses into the three categories. At an empirical level, the hypothesis remains entirely untested. Mercer himself did not attempt any systematic assessment of variation in time or space of both plans and social stratification nor has anyone rectified this omission. Despite this, the Mercer's interpretation has become the foundation for even more exotic interpretations in the English literature (e.g. Johnson 1989). Fortunately, the importance of Mercer's argument for the present work lies not in its empirical correctness, but in the fact that it has shaped the terms in which house plan variation in the Chesapeake has been conceived. As a result of Mercer's work, variation in the Chesapeake is presumed to be functional, something I hope to have demonstrated above. It is also thought to be correlated with the character of social relationships between farm owners and their workers.

The second component of the architectural-historical synthesis, was serious fieldwork on surviving structures in Virginia and Maryland. It revealed that the earliest Chesapeake houses to survive to today were predominantly of the 2-unit, end-chimney, end-entry type. Initially these were dated to the later seventeenth century, based on intuitive appraisals of stylistic features (Carson 1974). Subsequent dendrochronological work has shown that most of them in fact date to the 1690's or early 18th century (Heikkenen and Edwards 1983).

The English literature and Chesapeake fieldwork made it apparent that there was a contrast between the plans types that must have been part of the cultural repertoire of English migrants to the Chesapeake in the 17th century and the plans types that were actually found in extant 18th-century structures built by their descendants. That the alteration in plans was not something that occurred immediately on arrival to the Chesapeake was suggested by the results of archaeological excavations undertaken in the 1970's (Stone 1974, Noel Hume 1982, Kelso 1984) that began to reveal that many of the traditional English plan types, which were not represented in later extant Chesapeake structures, had in fact been built during the 17th century. This made it seem likely that any satisfactory explanation for the changes implied would have to involve alterations in environmental conditions that occurred in the Chesapeake during the 17th century. Three hypotheses have been offered and are reviewed below.

Carson (1978), pointed to the prevalence of plans characterized by lobby entries and central chimneys in the southeast of England and noted the occurrence of this feature in the 17th-century Chesapeake, for example at St. John's (18 ST 1-23) in St. Mary's City, built about 1636 (Stone 1974, 1982). Although not explicitly articulated, the argument was based on a migration model (Equation 3.9). Carson reasoned that, since two thirds of the immigrants to the Chesapeake were from the southeast, three-unit, lobby-entry plans (3/L/C) should have been much more common than evidence from extant structures from the early 18th century, dominated by two-unit, end-entry plans (2/E/E), indicated they were. This departure from expectations was a function of the increased need by planters for segregation from their indentured servants and later slaves, needs that lobby-entry plans could not fill. Note the contrast here with Mercer's interpretation of the lobby entry.

Carson suggested that two-unit plans were derived from 3-unit, end-entry plans (e.g. 3/E/CE) common in the west of England during the 16th and 17th centuries. Extant English examples show that such houses were divided using non-communicating partitions to make most of the house inaccessible from the unit containing the entry, a heated room, and the floors over it (Carson 1976). This end unit of the house often served as a food preparation and processing area, while the rooms over it provided servant accommodation. They therefore offered means of spatially segregating servants, their living space, and service activities from most of the house by confining them to the end unit containing the entry. The two-unit plans of the 18th-century Chesapeake were derived from this arrangement, when the end unit of the 3-unit plan was detached from it to become a separate kitchen. Chesapeake planters went to these extremes because their laborers were unfamiliar to them. By contrast, farm laborers in England were typically recruited by their masters from the same village or one next door.

The second major contribution to the problem is to be found in Upton's dissertation (1980). Upton attempted to pinpoint just when during the 17th century the traditional English plan types were dropped from the Chesapeake architectural repertoire. The data with which he attempted to do this were derived from probate inventories. These documents are lists of an individual's possessions, along with valuations of them, made at his death by a group of his peers appointed by the county court. When confronted with a large estate, the appraisers occasionally listed the estate's contents room-by-room, presumably as a way of helping to keep track of which objects and areas had been appraised. Upton collected room-by-room inventories dating from 1640 to 1720 extant in the Virginia county records, counting the number of named rooms in each. The results were summarized in terms of the mean and frequency distribution of numbers of rooms per house in successive decades. The pattern alleged to reside in these data is one in which house size increased from the 1640's, reaching a peak in the 1690's, and then declined during the early 18th century. Upton argued that the peak in the 1690's represented the accommodation of large numbers of servants in their master's houses. The need for such increased accommodation was the result of a great influx in servants into the colony that Craven (1971) claimed occurred in the third quarter of the century. For Upton, the subsequent decline in mean house size was an indication that most planters removed spaces for housing laborers and their work functions from their houses and placed them in separate outbuildings, that is kitchens and servants' quarters (Upton 1980:170-172).

Although this argument has been favorably received (e.g. Deetz 1988), there are numerous empirical problems with it. In the first place, the data on mean house size are themselves problematic. Mean house size estimates computed from Upton's raw data (1980:159) do not agree with either the decennial means (p.160) or the frequency distributions (p.155, Deetz 1988:366) cited as evidence. Hence the measurements on which the entire argument is based are in doubt. More damaging is the fact -- recognized by Upton in a footnote (p.154) -- that the named rooms he counted include rooms in outbuildings. There is no way to tell whether a room listed as "kitchen" is a separate structure. Hence the room counts are more a function of plantation size than of house size. There is also the problematic nature of the room-by-room probate inventories themselves. It is unclear to what extent variability in room number is a function plantation or house size or of idiosyncratic or culturally transmitted variation in the completeness with which appraisers named all the rooms that they encountered. In other words, the probate room counts are not reliable measures of actual room numbers. There are also problems with the other half of the argument: the character of the environmental changes that are alleged to have caused changes in room number. An unexplained 25-year gap separates the end of Craven's influx of servants (c. 1675) and the beginnings of the alleged decline in house size. Finally, historical research subsequent to Craven's (e.g. Menard 1977:362, and references therein) suggests that Craven's influx of servants never, in fact, occurred.

In a first treatment of The Clifts Plantation, an archaeological site on the south shore of the Potomac River that the subject of the following chapters, I suggested on the basis of the timing of architectural changes, that servants and servant-related activities were excluded from the main dwelling during the 1680's (Neiman 1978,1980b). As we shall see, this chronological assessment was an error. However, it fit nicely with the notion that the alterations in plan forms were the result primarily of social factors, in particular of a growing "social distance" between planters and their laborers. The transition to slavery was only the final aspect of this trend, itself preceded by two other developments. The first of these was an increase in the importance of Irishmen and poorer Englishmen as servants, as an initial consequence of the developing labor shortage to which slavery would prove the ultimate solution (Menard 1977:380, 1975:414-417). The second was a complementary growth in the number of Chesapeake-born planters whose personal experience never included servitude. The fact that the architectural changes at the Clifts appeared to precede the switch to slave labor at the site, whose timing was documented by excavation of the plantation's cemetery, pointed to the importance of the changing social origins of indentured servants in the process (Neiman 1980:34-35).

5.4.5 Alternative Hypotheses

I have noted above the inadequacies of the three arguments as descriptions of variation in artifact form. In addition all three of these treatments suffer from varying degrees of theoretical incompleteness. The first missing feature is any sort of explicit account of the mechanisms that converted changes in environmental parameters, that is the character of labor force, or in the case of Upton their numbers, into the differential persistence of house plans. All seem to rely on similar unarticulated, "common sense" generalizations about human behavior. At the foundation of all the accounts is the implicit assumption that individuals find it unpleasant to associate with others whose behavioral phenotypes are strange or different from their own. Such an aversion, if it exists, would constitute a learning rule directly-biasing individuals in favor of means of organizing work on plantations that minimized the rate of interaction between planters and laborers, as the ontogenetic experience of the two groups diverged. This notion fits with a recent proposal by Bateson (1983), in the context of proscriptions against incest, that individuals tend to have positive responses to slightly novel social stimuli but strong, negative ones to conspecifics who behave in unfamiliar ways. The idea has deep roots in psychology where it is known as the discrepancy hypothesis. I shall borrow the term and use it to refer collectively to all explanations of house-plan sorting that invoke this rule. The discrepancy hypothesis suggests that, as plantation owners found themselves confronted with a labor force whose cultural backgrounds and resulting behavior were increasingly different from their own, they favored production arrangements that minimized contact with laborers. Whether the necessary stimulus came from growth in the proportions of enslaved Africans or Irish and poor English servants in the labor force is an empirical matter.

As I have suggested in previous chapters, in an evolutionary context, any explanation that relies on biased transmission is fundamentally incomplete without an account of the context in which the learning rule was fixed by natural selection. Explicit recognition of the fact that learning rules have evolutionary origins brings with it a beneficial theoretical constraint on the kinds of rules that might be invoked to account for phenomena. Over the long term, this in turn can be expected to both guide in productive directions and minimize ad hocism in the research program designed to catalogue the rules. Since none of the research described above was conducted in an evolutionary framework, it is no surprise that the workers responsible for it have felt no need to acknowledge explicitly the pivotal role the learning rule plays in their explanations or to offer an account of its evolutionary origins. This is an initial reason for skepticism concerning the accounts based upon it. I cannot offer here an evolutionary explanation for the existence of such a learning rule. Previous sociobiological attempts along these lines (Barash 1979:154), relying on kin selection, have suffered obvious fatal theoretical flaws (Kitcher 1985:252-56). This is not to say, however, that a satisfactory account is impossible.

The second hypothesis for the causes of deterministic sorting of house-plan types suggests that the crucial environmental alterations were the economic stresses that affected tobacco planters in the Chesapeake toward the end of the 17th century. Under this economic hypothesis, the effects on the house-plan repertoire were mediated by indirect bias rules keyed on resource acquisition rates or wealth. Values of these two indicator traits were a function of production costs and productivity. These in turn were conditioned by culturally transmitted prescriptions for organizing production and cultivation technique. From the begining of settlement then we can expect sorting pressure in favor of variants that resulted in lower production costs and greater productivity. However, there is reason to suspect that pressure was not uniform across the 17th-century.

Recall that tobacco prices declined across the century. To some extent the effects of the decline on producers, in terms of net income, were offset by increases in productivity of their laborers. Menard (1980:145) has assembled data on productivity from contemporary observations across the century. These data show that the mean amount of tobacco an individual could produce per year began to increase about 1640 and doubled over the next thirty years before stagnating. It remained constant over the next century. There is some contemporary documentary evidence that productivity gains came from improved methods of transplanting and harvesting tobacco plants. A smoothed curve through Menard's data has the familiar sigmoid shape characteristic of deterministic sorting. Note the coincidence in timing with the jump in distance moved in the settlemnt spread curve. While productivity gains ceased in the 1670's, tobacco prices continued to fall. Prices finally bottomed out in the late 1680's, but they remained below the levels of the 70's until c. 1720.

After productivity gains stagnated in the 1670's, variability in resource acquisition rates for tobacco planters, and hence their contribution in horizontal transmission networks, would be entirely a function of costs of production. Costs associated with inefficient strategies for organizing production could no longer be offset by high productivity per laborer. Hence after 1670, we can expect increased sorting pressure, via complex indirect bias, in favor of ways of organizing plantation work that caused lower costs of production for planters. This pressure would be enhanced by deterioration of the economic environment that characterized the last quarter of the 17th century and the first quarter of the 18th century. As a consequence of the causal connection between secondary and indicator characteristics, and the demise of the cushion provided by variability in productivity per laborer, such secondary variants were driven to fixation. Initially, form-behavior variants would be favored that lowered the amount and cost of household resources consumed by laborers. However, evolutionary theory suggests that the processes involved under this sorting regime would have been more complex than this.

Recall our earlier discussion of the importance of costly learning rules in the context of social interaction (Section 2.4). The past decade has seen considerable theoretical work, based on Maynard Smith's ESS approach (Section 2.2), on the leaning rules that might underlie variation in cooperative interactions among conspecifics. The game-theoretic metaphor for cooperation is the Iterated Prisoner's Dilemma, a two-player game in which both players can reap a high fitness payoff by cooperating in a given interaction, but an even higher payoff can be had by one player by defecting on the other cooperating player. If both players defect, their fitness is less than if they had cooperated, but greater than a cooperating player gains in the face of defection. Axelrod and Hamilton (1981, Axelrod 1984) showed that one strategy, tit for tat (TFT), is evolutionarily stable against invasion by a wide variety of other strategies, including constant defection. An individual employing TFT will cooperate with another player, as long as that player cooperated in the previous interaction, but will defect if the other player defected. TFT-like reciprocity has been documented in non-human primates (Seyfarth and Cheney 1984). More recently, Cosmides has presented experimental evidence to support the idea that human social behavior is guided by individual learning rules, designed by natural selection, that enable detection of defectors and TFT-like retaliatory response (Cosmides 1989, Cosmides and Toobey 1989).

Given the fixation of such rules, it is expected that the increasing frequency of cost-reduction strategies in the behavioral repertoires of plantation owners would be recognized as defections by laborers. TFT learning rules would favor the introduction and/or spread of retaliatory behaviors, via guided variation and directly biased transmission respectively. Effective TFT learning rules would favor behaviors that raised the value of fitness correlates (e.g. resource availability) for laborers, while lowering them for owners. The expectation is for an increase in the frequency of illicit acquisition of owner's household resources by laborers. Thus TFT retaliation by laborers would further increase economic sorting pressures on owner production strategies in general, and in particular on those aspects of production strategies that affected probability of resource loss through theft. The economic hypotheses suggests that the changes in plan forms described above were the outcome of this causal chain.

5.4.6 Behavioral Inference and Site Structure

The previous sections have documented what appears to be deterministic sorting of functional artifactual variants and described two possible mechanisms and the environmental variables that engendered the operation of each. At this level of analysis, the connection between the house-core plan changes and their two hypothesized causes is correlational, based entirely on the coincidence of timing between hypothesized causes and archaeologically documented effects. The missing ingredient in a completely specified model of the hypothesized causal dynamics is an account of the behavioral variants that were sorted along with variant house plans. Such an account is the product of what I have called the functional-morphological approach to archaeological inference.

In Chapter 4, we saw how making behavioral inferences requires hypotheses concerning the mechanisms responsible for sorting behaviors and artifact forms in a given environment. Two sets of causal links or mechanisms are relevant in the present context. The first is a general set of learning rules, apparently shared by modern humans, governing structuring and use of living space. The second is comprised of the alternative mechanisms hypothesized to have been responsible for the architectural changes documented in the Chesapeake. The second of these two sets of mechanisms has been outlined above. It remains then to describe the first and to suggest how both make possible behavioral inferences from house-plan variation.

Over the past decade, archaeologists have begun to document ethnographically what appear to be pan-human patterns in the way in which individual activities that are part of a group's behavioral repertoire are located in space in relationship to one another on domestic sites. The patterns emerge across a variety cultural contexts: foraging groups like the !Kung (Yellen 1977) and Alyawara (O'Connell 1987), logistically organized hunters exemplified by the Nunamiut (Binford 1983, 1987), and sedentary agriculturalists like the Basarwa (Hitchcock 1987) The number of case studies is small, and most of them have dealt with hunter-gatherers. However, existence of pattern across unrelated groups adapted to vastly different environments and across both traditional and modern activities within groups is compatible with the notion that it is caused by individual learning rules (guided variation) fixed by natural selection. Rather than offer a review of this research, I provide a short, tentative, and necessarily speculative summary of its results. The regularities that emerge can be described in terms of a subtractive model that specifies the conditions under which certain activities are likely to be located in spatially segregated areas away from others.

The crucial variable that controls activity segregation in space is the extent to which activities interfere with one another. Interference is likely when some subset of tasks requires large amounts of space either because the objects processed take up large amounts of space or because the work generates large amounts of refuse, or because the work requires large amounts of uninterrupted time. Each of these factors, singly or in concert, renders simultaneous use of the same space for other purposes costly in proximate terms of time or energy expenditure. They make it more likely that the interfering activities will be removed to special-activity areas. Furthermore, when multiple special activities generate interference, and they cannot be sequentially scheduled, each will be removed to its own area.

On the other hand, additional energy will not be expended to remove to such areas activities that require smaller amounts of space, generate little refuse, or have short durations. These activities will therefore tend to occur together in the same general-activity area. Economies of access from a (single) general-activity area to multiple special-activity areas dictate that the former will be centrally located on habitation sites, while the latter will be located peripherally. Thus when behavioral repertoires include interfering activities, we can expect habitation sites to be divided between a general-activity area and special-activity areas scattered around it. Pushing the argument further, the size of special-activity areas should be a function of the bulk of the items being handled or of the refuse they generate. The distance they are removed to the site periphery should scale with the frequency with which individuals access these areas during the day.

Archaeologists have yet to reach a consensus on the terms to denote this widely appreciated distinction. General-activity areas have been called nuclear (Yellen 1977), intensive (Binford 1983), and household activity areas. O'Connell's (1987) special-activity areas are equivalent to Binford's extensive activity areas.

General-activity areas can be expected to house activities like eating and preparation of food for immediate consumption, sleeping, and social interaction. Thus they typically will include hearths and sleeping areas. Whether these are incorporated into some form of shelter is a function of climate and group mobility (e.g. O'Connell 1987). There is more variability in the kinds of activities pursued in special-purpose areas across and within cultural contexts. For example, among Australian aboriginal groups, kangaroo roasting pits and automobile repair locations are similarly segregated from general-activity areas because both kangaroos and cars are large. Special-activity areas are especially prevalent among groups relying for year-round subsistence on resources that are only available on a seasonal basis, and then typically in great quantity. For these groups, bulk processing of large quantities of food to prepare it for long-term storage is a crucial part of subsistence. Here special-activity areas will tend to fall into two groups: locations at which bulk processing itself is carried out and areas where processed items are stored. Processing is carried out on a large scale and is likely to generate large quantities of refuse, while storage requires extended periods of time without disturbance. Bulk processing for storage can be found among hunter-gatherers like the Nunamiut where the items processed for year-long storage are caribou procured during seasonal mass kills (Binford 1983:188). Of more relevance in the current context is the importance of bulk processing and storage to agricultural systems where seasonal resource availability is the norm. (e.g. Hitchcock 1987).

Bulk processing for storage was a crucial aspect of the agricultural and husbandry strategies pursued in the Chesapeake. Although not a food crop, tobacco was a high-bulk substance that required special-purpose facilities for drying and later packing dried leaves for shipment. Maize, which served as a the staple food, was also a high-bulk crop that required fall harvesting, followed by shucking and shelling for storage. Animal products of various kinds also fall in this category. Faunal assemblages attest to the importance of cows and pigs as meat sources (Miller 1984). Both species are too large to be consumed by a single-family group over a few days and require preservation and storage upon slaughter if meat is not to be wasted. Cow's milk, a traditional protein stable among English peasants, required intensive processing for preservation as cheese and butter.

Given the importance of interference-generating activities to early Chesapeake adaptations from the very beginning of English settlement, we can expect habitation sites to be partitioned into general-activity areas and special-activity areas for bulk processing and storage. Just how this partitioning was accomplished was historically variable. Despite the fact that dwellings represent only a small part of site layouts, the foregoing arguments can be turned to account in suggesting the behavioral significance of house-plan variation early in the century. Recall that on the basis of documentary evidence English architecturai historians have regarded the third room of three-unit houses as a "service room." Given the framework developed above, it becomes clear that that this attribution can be given theoretical justification and that service rooms may be considered special-activity areas for bulk processing and storage that were housed in the same structure as general-purpose living space. This perspective also suggests that much of the temporal and regional variation in size and the presence or absence of heat in the third room in an English context from the 16th and 17th centuries may be linked to variability in the scale of bulk processing and in whether or not heat was required to do it. In any case, the rules governing the use of space, taken in conjunction with the prevalence of three-unit and half-unit plans in the early Chesapeake architectural repertoire, are compatible with the notion that these architectural forms were used in behavioral contexts characterized by the location of some bulk-processing and storage activities within dwellings.

As we have seen these same elements are the ones that disappear from the Chesapeake architectural repertoire at the end of the century. If the learning rules outlined above were the only forces at work in this situation, we would be entitled to infer that bulk processing and storage ceased to be important components of the Chesapeake behavioral repertoire. We know that this inference is incorrect. And our two alternative hypotheses concerning the causes of deterministic sorting of plan types late in the century emerge as strong alternative candidates for the additional force whose operation must be considered in determining the behavioral significance of house-plan changes. Under both hypotheses the demise of three-unit and half-unit plans signals the removal of special-activity areas for bulk processing and/or storage from dwellings. The remaining one and two-unit plans represent houses from which these activities had been removed to outbuildings. Under the discrepancy hypothesis the positively evaluated consequence of the change was the minimization of social contact between planters and their laborers. Under the economic hypothesis, the causally relevant practical effect was the minimization of physical access for laborers to the dwelling and thus opportunities for household resource loss through theft.

Implicit in earlier treatments (Upton 1980, Neiman 1978, 1980) is the notion, borrowed from Mercer (1975), that the during the early part of the century, that planters' dwellings housed not only work areas for laborers, but also areas in which servants slept, prepared and consumed food, and socialized. This sort of arrangement is alleged to have come to an end at the close of the century, as servants were shunted off into separate quarters. The variation monitored in the two classifications of house-core plans does not address this issue. To make inferences on this topic possible, we require systematic documentation of both dwelling and entire-site layouts and chronologies of alterations in them. Given wide variability in the extent of horizontal exposures from site to site and the persistent lack of intrasite chronology construction that characterizes archaeological work to date, the required evidence is simply not available in sufficient quantity to make possible meaningful descriptions of the trajectory of change in site layouts, comparable to those offered for house plans.

However, it is worth briefly considering what site-layout alterations could be anticipated, if these behavioral scenarios were correct. Here again the discussion of activity-area structure becomes useful. Food preparation and consumption, sleeping, and socializing are precisely the kinds of activities that typify general activity areas. This means that we should expect to find early plantation sites comprised of a single general activity area, while later ones will tend to be characterized by two, one utilized by planter-family members and the other by laborers. Under the discrepancy hypothesis the positively evaluated consequence of these new spatial arrangements was once again minimization of contact between the two groups. Under the economic hypothesis, the relevant effect was a decline in the costs of feeding and housing servants, made possible by placing them in separate living areas and on separate diets. This formulation in terms of single vs. multiple general-activity areas will prove useful in the next chapter, when we examine changes in the layout of a single plantation site.

Finally it should be noted that the behavioral inferences from house-plan changes outlined above imply changes in site layouts, in particular the construction of outbuildings to house bulk processing and storage activities that were removed from the dwelling. This leads us to expect an increase over the century in the proportion of sites with outbuildings and in the number of outbuildings on sites. Here again, the data for a systematic description of variation among sites are not available. However, as we shall see in the next chapter, data for a single plantation are.

5.4.7 Toward Hypothesis Tests

Two important questions remain unanswered. First, are either of the two hypotheses likely to be correct? Second, which of them better accounts for the archaeological evidence? In the following chapter I attack these questions on several fronts, using data from a single Virginia plantation occupied during the late-17th and early-18th centuries.

One way to address the first of these questions is to evaluate the extent to which changes in activity organization inferred on the basis of architectural evidence match inferences from an independent source of artifactual evidence: the horizontal distribution of ceramic types across sites. As we have seen above, the two alternative hypotheses lead to broadly similar behavioral inferences. Hence this strategy is not a means of discriminating between them. But it does offer an opportunity for their joint rejection.

There are two strategies for answering our second question. One is based on developing contrasting expectations concerning patterning in the archaeological record under each hypothesis using the consequence laws reviewed in Chapters 3 and 4. If the economic hypothesis is correct, we can expect to see evidence of lowered rates of resource acquisition on late 17th-century plantations characterized by the plan types that disappeared from the architectural repertoire at that time. In extreme cases, we might also expect to find replacement of individual planters using one set of strategies by planters using another, a circumstance that will be detectable archaeologically if the two owners were derived from segments of Chesapeake society that differed in terms of style or wealth. The discrepancy hypothesis, since it turns on direct-bias learning rules that are fixed in the population, predicts household continuity in time across plan changes. In other words, it suggests that individuals "decide" to implement plan changes when exposed to the proper stimulus, increasing cultural difference between themslevs and the labor force. Thus we can further expect changes in the cultural background of the labor force to be more-or-less coincident with plan changes on individual plantations within a local area over which cultural transmission linked their owners.

The second approach, based on source laws, would attempt to develop contrasting expectations concerning the kinds of architectural variation that might be favored under the two hypotheses. For example, the economic hypothesis entails constraints on the spatial organization of activities that the discrepancy hypothesis does not. In particular, the removal of bulk processing from the dwelling brings with it a potential loss in the ability of owners to oversee these operations. Decreasing probabilities of loss of household valuables brings with it an increase in probability of loss of resources that servants process. One strategy by which the latter possibility might be circumvented is through the spatial arrangement of activities in such a way as to minimize the number of different kinds of resources to which laborers have access when processing any given resource. Thus, for example, laborers processing corn for storage would have access only to stored corn and not other resources. A second favorable result would be an increase in the ease with which surveillance of laborers at work could be undertaken. Individuals who were out of place would be easily identified. The expected result would be an increase in the number of special-purpose processing and storage locations in the form of outbuildings. By contrast, on the discrepancy hypothesis, a only a few multiple-use outbuildings might be expected.

These tests are the subject of the following two chapters. The data that they require are from a single Virginia site, The Clifts Plantation, occupied during the late-17th and early-18th century. However, before proceeding to a presentation of that evidence, two tests of the two hypotheses are possible, based on the house plan evidence already in hand.

The first rests on contrasting expectations derived from consequence laws concerning temporal patterning in house plan variation. Both the discrepancy and economic hypotheses lead to the expectation of a period of strong deterministic sorting at the end of the century. However, the economic hypothesis suggests in addition that sorting of house plans should have been present from the beginning of settlement. As usual the small size of the house plan sample makes conclusions suspect. However, both the classifications used to measure house plan variation (Tables 5.2 and 5.3) appear to exhibit declining diversity after c. 1640.

The second test depends upon using the source-law approach to develop contrasting expectations concerning plan types that should be favored under the two hypotheses. That evidence is already in hand (Table 5.2). Recall that central chimneys and lobby entries disappeared from the sample at the end of the 17th century to be replaced by direct entries and end chimneys. In the sample, the two pairs of variables are nearly perfectly correlated. Assuming that individuals tend to learn the value of both dimensions from the same model, explaining the replacement or one pair by the other is a single problem.

On the discrepancy hypothesis, we expect lobby entries to be favored for much the same reasons Mercer thought they were favored among prosperous farmers in economically stratified areas around London: separate access to the parlor, unencumbered by passage through the hall. Even after servants and service activities had been removed from the house this would appear to be a valued feature. As Upton puts the matter "servants still had to come and go" (1980:212). Indirect entry into a lobby would appear to be a more effective way of insulating the house interior and its occupants from the occasional dealings with servants than direct entry into a hall. In fact, defenders of the discrepancy hypothesis argue that porches or enclosures over entries, became popular about this time for precisely these reasons (e.g. Neiman 1978).

On the other hand, the economic hypothesis suggests that plans with direct entry would have been favored. In an economic context, the fundamental disadvantage of the lobby entry was that it made monitoring access to the house difficult for its occupants. The lobby would have prevented individuals located in either of the two rooms from being able to observe and hence control access to the other. Plans with direct entry into one of the rooms do not share this defect. Individuals installed in the hall could see anyone entering and occupants of the inner room may observe a at least a portion of the space in the hall through the door connecting the two rooms. The advantage of the direct-entry plan lay in the ease with which surveillance of traffic through the house could be conducted.

Chapter 6

The Clifts Plantation Site

6 Introduction

The previous chapter offered two alternative hypotheses concerning the mechanisms responsible for deterministic sorting of house-plan types in the Chesapeake at the close of the 17th century. The remainder of this work is devoted to exploring which of these two hypotheses better accounts for stylistic and functional variation, in time and space, in the archaeological record of The Clifts Plantation Site.

First I offer a short account of what little is known about the site and its occupants from the documentary record. I then turn to the crucial task of inferring a fine-grained chronological framework in which the trajectory of change at the site can be measured. This framework makes it possible to document changes in the internal arrangement of the principle dwelling at the site and in the layout of structures around it. Alterations to the principal dwelling at The Clifts mirror those already described for the region as a whole. They can be related to changes in the layout of the site and the behavioral significance of both inferred by extending the functional-morphological arguments developed in the previous chapter (Section 5.4.6). This sets the stage for the next chapter in which the inferences about the behavioral significance of architectural changes are tested using evidence from the horizontal distribution of artifacts recovered from plowzone across the site. The congruence of behavioral inferences based on architectural and distributional evidence suggests that our two hypotheses should not be rejected on these grounds. Hence it becomes a matter of deciding between them. The fine-grained site chronology makes it possible to document temporal dynamics of stylistic and functional elements and thereby to determine whether changes in the arrangement and use of architectural space occurred in the context of population replacement and economic failure or of household continuity across change in the social character of the labor force.

6.1 Documentary Evidence

The Clifts Plantation (44 WM 33) is located on the south shore of the Potomac River in Westmoreland County, Virginia. The site lies on a tract of land now owned by the Robert E. Lee Memorial Association, Inc., a group devoted to the preservation of Stratford Hall, an 18th-century mansion that was the birthplace of Robert E. Lee.

Permanent English settlement of Westmoreland began in the late 1640's. By 1653 it had attained sufficient density to warrant the institution of local political structure that accompanied formation of the county itself. Thus Westmoreland was occupied during the punctuation in settlement spread documented in the previous chapter. Many of the earliest settlers in the region were immigrants from Maryland, among them Nathanial Pope, who first patented the land on which The Clifts was located in 1651 (Virginia Land Patents 4:32). Pope, who lived up river from the Clifts tract at the confluence of Mattox (Appomattox) Creek and the Potomac, was among the county's wealthiest residents at his death in 1660 when he left The Clifts tract to his son Thomas (Westmoreland 10:115). Thomas Pope turns up in the Westmoreland County court records sporadically through the ensuing 25 years as a "planter of Westmoreland" and "merchant of Bristol" (Westmoreland 4:89,266, V:404). During his stays in Virginia, he occupied a plantation located at the mouth of Pope's Creek at the western edge of 2450 contiguous acres that included The Clifts. Archaeological evidence indicates that The Clifts tract, comprising the eastern half of Thomas Pope's 2450 acres, was first occcupied during this period, presumably as a tenant farm.

At Thomas' death in 1685, the Clifts portion of his property passed to his sons, Richard and John, with a dower interest to his wife, Joanna, who acquired another third at John's death in 1700 (Westmoreland 15:324). Joanna Pope appears to have remained a Bristol resident during her entire life. Thomas' youngest son, Nathaniel, appears in the county's records for the first time in 1704 when he married the daughter of a Westmoreland Justice of the Peace (Westmoreland 8:260). Like his father, he appears to have pursued a career on both sides of the Atlantic, being styled both "merchant" and "mariner" (Westmoreland 7:59,327). In 1708 his mother gave him power of attorney to manage The Clifts. The letter of attorney refers to her son as "Nathanial Pope of Pope's Creek" (Richmond 5:116-117). The phrase does little to resolve the ambiguity of whether or not Nathaniel and his wife actually resided at The Clifts. His wife's deceased first husband owned land on Pope's Creek and The Clifts is situated three miles down river from it (Westmoreland 17:246).

In 1716 Joanna and Richard Pope sold the Clifts, including what was referred to in the deed as "the manner house erected on the second clift," to Thomas Lee (Westmoreland 15:324-345). While the Popes had circulated the among members of Westmoreland County's political elite, Lee's family had been part of the colony-wide elite for two generations. Lee himself would become a member of the Governor's

Council and eventually acting governor of the colony. Up until 1729, Lee lived at his father's plantation on Lower Machodoc Creek, when the dwelling burned to the ground. Sometime thereafter he erected the brick mansion, today known as Stratford Hall, on the Clifts tract about a quarter mile from site of The Clifts (Wyrick 1971). The "manner house" and the buildings surrounding it were demolished to make way for a road running between Lee's new mansion and a landing on the shore of the Potomac. Recent dendrochronological results place the construction of Stratford in 1740. They raise the question of the location of Lee's residence in the decade following 1729. The Clifts is a possibility, but there is no documentary evidence to make it more than that. Archaeological evidence indicates occupation of the site continued at least until 1730.

The details of the occupational history of The Clifts are of special importance in the current context. Recall that the economic hypothesis leads us to expect that some plantations will suffer economic failure followed by replacement of the original occupants by individuals following economically more viable strategies. The documentary record at The Clifts is too scanty to support such inferences. The history of ownership is unilluminating in this regard because the first two owners, Thomas and then Joanna Pope, are known to have lived elsewhere during the entire period they were associated with the site. The same can be said for Thomas Lee up to 1729.

A second and more general point concerning written evidence is relevant here. In current practice in historical archaeology, historical documents provide the foundation on which the imputation of meaning to the archaeological record rests. Any and all differences isolated between two archaeological assemblages, known from documents to have been generated by individuals who differ on some arbitrarily chosen, historically documented dimension of variation, are alleged to have been caused by that dimension (e.g. South 1977:31-43, Rockman and Rothschild 1984). Used in this fashion, documents become obstacles to the use of a theoretical framework that alone makes it possible to lay bare the causal connections between archaeologically and historically monitored variation. This is not to say that documents are irrelevant to archaeological inquiry, but that they should be used to test hypotheses concerning the meaning of archaeological variation that have been generated on the basis of archaeological theory. In the case of The Clifts, the lack of definitive evidence concerning the identity of it's occupants precludes the pursuit of the usual strategy, making especially apparent the need for a more theoretical approach of the sort advocated in previous chapters. However, even if documents did provide a complete list of the plantation's occupants, we would still require the archaeological theory and evidence to infer whether or not occupant succession was a consequence of the deterministic sorting of house plans under investigation here.

6.2 Chronology

The architectural layout of the site throughout the 60-to-70 year occupation was conditioned by the immediately surrounding topography. The principal dwelling -- the "manner house" of the 1716 deed -- and the surrounding cluster of structures are situated on a finger of dissected upland. About 1300 feet to the north lies a cliff, one of a series of bluffs that stretch along the Potomac shore, plunging roughly 130 feet to the river. About 160 feet to the west of the dwelling lies a steep-sided ravine in which a spring surfaces. In the absence of a well, this was the water source for the site during its occupation. To the east of the dwelling the land slopes off more gently. The area to the west of the dwelling, and closest to water, was the site of most of the ancillary structures on the site, while the land to the east was the site of large fenced enclosure, presumably a garden.

The basic architectural elements of the site can be enumerated quickly (Figure 6.1). All buildings were framed around hole-set posts. At the center of the site lay the principal dwelling (Structure 1). It was surrounded by a palisade fence with bastions on opposite corners. Just to the southwest lay two superimposed, and hence successively built, secondary domestic structures (Structures 2 and 3). These buildings, and similar ones on other sites, have conventionally been called "quarters" (e.g. Keeler 1977, Neiman 1980a, Pogue 1988). The convention is potentially dangerous because it implies they had similar uses in general and specifically were used to house laborers. Both these implications are inferences, a fact that the label obscures. The label also obscures the possibility that the manner in which such structures were used may have changed over time. However, since the term is entrenched in the literature of the region, I shall continue to use it.

Arrayed in an arc to the west of the dwelling and the quarters lay a series of 9 small, single-bay outbuildings (Structures 4-12). Among them were interspersed numerous, irregularly shaped pits, dug into subsoil and filled with artifact-laden sediments. To the east, on the opposite side of the dwelling, lay the remains of two successive fence systems, one comprised of ditch-set uprights, the other of hole-set posts. On the eastern edge of the garden, were 18 grave shafts, 16 of which contained human

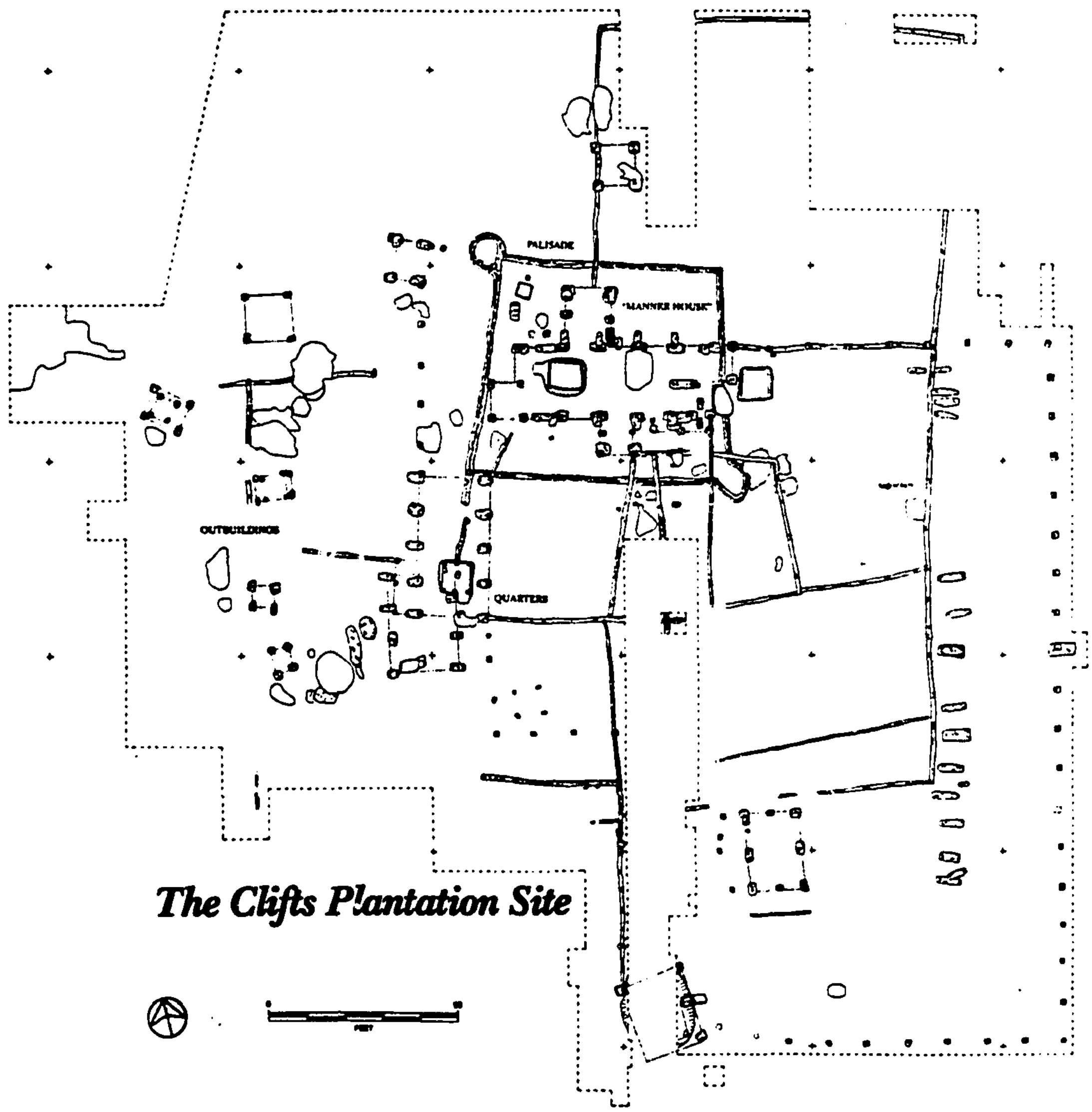


Figure 6.1 Architectural layout of The Clifts Plantation Site.

skeletal remains. Finally, a pair of larger, two-bay outbuildings lay on the southern end of the garden (Structures 13 and 14).

6.2.1 Seriation

The examination of change in the arrangement and use of these structures requires the inference of a fine-grained chronological framework. I have constructed one using the method of occurrence seriation (Rouse 1967, Dunnell 1970). Behind the method is a model that predicts that the occurrence of types through time is continuous. Unlike frequency seriation, there are no requirements concerning the shape of trajectories. This generality means that the types employed in an occurrence seriation can monitor stylistic or functional traits, or mixtures of both, without adversely affecting the results. Since the temporal resolution achieved in an occurrence seriation is a function of the number of traits with unique beginnings and terminations, a mixture of stylistic and functional variation may even be desirable. The only requirement is that the types be historically unique.

The types employed in the occurrence seriation at The Clifts are based on the categories traditionally used by historical archaeologists, which in turn are defined in terms of paste, glaze, and firing temperature (Noel Hume 1972, South 1977). These are supplemented with the addition of a category which I shall call "Table Glass," clear glass sherds whose curved sides indicate their derivation from vessels and not window panes. The process of choosing which of the ceramic types should be included has been one of trial and error. We require types that are not only historically continuous, but also numerous enough to have a good chance of turning up in any assemblage that is contained in a deposit sealed after the time they were introduced to the site. Hence only the more common ceramic types are included. Sampling considerations also apply to the assemblages that are seriated. They must be large enough to have a good chance of containing all of the recognized types that had been introduced to the site at the time they were interred. The assemblages are derived from either large features (e.g. pits or cellars) or groups of smaller features whose contents and spatial arrangement indicate contemporaneity of their deposits (e.g. post holes belonging to a single structure).

There is a final ingredient. The seriation model specifies merely that the occurrence of types through time is continuous. This is sufficient for cases in which assemblage acuity, monitored at the level of type occurrences, is constant or even a random variable about a constant expectation. However, when acuity scales inversely with time, that is, early assemblages have high acuity while later ones have low acuity, ambiguity may result. Under these conditions, types that were in use early in an occupation will turn up in assemblages sealed long after those same types ceased being used. Such effects are likely when formation processes include redepositional cycles in which artifacts are stored temporarily in deposits from which sediments are derived to fill later deposits, some of which remain undisturbed until

Table 6.1 Alternative seriations with redeposition. A. Incorrect order permitted by traditional model. B. Correct order on revised model.

A.

Types: / Units	A	B	C	D
2	1	1		
5	1	1	1	
6	1	1	1	1
4	1	1	1	
3	1	1		
1	1			

B.

Types: / Units	A	B	C	D
1	1			
2	1	1		
3	1	1		
4	1	1	1	
5	1	1	1	
6	1	1	1	1

archaeological recovery. If such effects are pervasive, they will lead to a situation in which not only are the distributions of type occurrences in assemblages temporally continuous, but they will be continuous to the end of the occupation as well.

The distinction is of practical importance when one attempts to execute an occurrence seriation. The traditional solution to the seriation problem is to find the permutation of rows (assemblages) of an occurrence matrix that minimizes the number of gaps between occurrences of types (Kendall 1963). When redeposition is important, there will be a large number of arrangements all of which are equally good in terms of number of gaps and many of which will be without chronological significance. In this case a second quantity must be minimized, the number of gaps between the initial occurrence of a type toward one end of the matrix, on the one hand, and the other end of the matrix on the other (Table 6.1). The fact that the rows of a matrix can be permuted so that all occurrences fall below a diagonal running across the matrix (e.g. Table 6.1 B) is *prima facie* evidence for the importance of redepositional cycles. In this case, unlike the case of the traditional seriation model, there is no ambiguity on which end of the matrix represents earlier assemblages. The Clifts seriation is an example.

The permutation of assemblages that minimized the second criterion discussed above is shown in Table 6.2. Given the pattern of occurrences, the 26 assemblages can be ordered into 14 distinguishable ranks. Strictly speaking the resulting ordering is an hypothesis concerning the temporal order of the end points of the periods over which the assemblages accumulated. That it is actually a chronology is an inference (Dunnell 1970). That the order also applies to the deposits that contain the assemblages is also an

Table 6.2 Occurrence seriation of assemblages from selected deposits at The Clifts.

TYPE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	RANK	PHASE
STRUCTURE 2																	1	1
STRUCTURE 1	1																2	1
PIT 346A-D	1	1															3	1
PIT 290A-D	1		1														4	1
PIT 289A-H	1	1	1														4	1
PIT 305A-G	1	1	1	1	1												5	2
PIT 273A-C	1	1	1	1	1	1											6	2
PITS 274AB,EG	1		1	1	1	1											6	2
PALISADE	1	1	1	1	1	1											6	2
PIT 250D-E	1	1	1		1	1	1										7	2
STRUCTURE 3	1	1	1	1	1	1	1										7	2
S1 REPAIRS 2-5	1	1	1	1	1	1	1										7	2
CELLAR 262AB	1	1	1	1	1		1	1									8	3
PIT 255F-Y	1	1	1		1	1	1	1									8	3
PIT 240F-G	1	1	1		1	1	1	1									8	3
FENCE DITCHES	1	1	1		1	1	1		1								9	3
PIT 288S-AD	1	1	1	1		1	1	1	1	1	1						10	3
PIT 255A-E	1	1	1	1	1	1	1	1	1	1	1						10	3
PIT 277A-C		1	1						1	1	1	1					11	4
PIT 345A-C		1	1	1			1	1	1	1		1					11	4
S16 CELLAR 365A-H	1	1	1	1		1	1	1	1			1	1				12	4
POST & RAIL FENCE	1	1	1		1	1	1	1				1	1	1			13	4
PIT 280A-H	1	1	1	1		1	1	1	1	1	1	1	1		1	1	14	4
PRIVY 231D-E	1	1	1	1	1	1	1	1	1	1		1		1	1	1	14	4
CELLAR 269A-F	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	14	4
S3 CELLAR 283S-N	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14	4

KEY TO TYPES: 1) Morgan Jones. 2) Tin-Glazed Earthenware. 3) North Devon Gravel-Tempered Earthenware. 4) Rhenish Brown Stoneware. 5) North Devon Sgraffito Earthenware. 6) Staffordshire Yellow Slip Earthenware. 7) Table Glass. 8) Burslem-Nottingham Stoneware. 9) Rhenish Blue-Gray Stoneware. 10) Staffordshire Brown Stoneware. 11) Black-Glazed Earthenware. 12) Slipped White Stoneware. 13) Buckley Earthenware. 14) Unslipped White Stoneware. 15) Staffordshire Brown Slip Earthenware. 16) Staffordshire Manganese-Mottled Slip Earthenware.

inference. Both these hypotheses receive some support from the fact that the assemblage order violates stratigraphic relationships among the deposits from which they are derived, in only 1 of the 15 cases where such relationships exist (Section 6.7.1). A second aspect of the seriation is the arrangement of columns (types) in the order in which they appear in assemblages. The resulting ranking represents the order in which the types were introduced to the site. This ordering is itself useful in dating assemblages, and by inference deposits, that were not included in the original seriation.

6.2.2 Supplementary Chronological Evidence

The seriation allows the occupation of The Clifts to be resolved into 15 periods, or more precisely, the assignment of a limited number of depositional units containing relatively large samples of artifacts to 15 periods. However, because the sizes of the assemblages they contain are small, many depositional units are not included. Other means must therefore be employed to fit such units into the chronology. With a given number of types, the fineness with which time can be resolved in a set of assemblages scales with their size. This means that if deposits containing small artifact samples are to be seriated, the seriation will have to be one based on fewer types and therefore result in less fine temporal resolution. Table 6.2 shows how the seriated assemblages at The Clifts were lumped into four major phases, each having 15-to-20 year durations. Each phase groups a set of assemblages and, more importantly, a set of types that were first introduced to the site during it. Each of the four type groups then can serve as a "type" for what in effect is a second, coarse-grained, occurrence seriation that includes many more assemblages. These smaller assemblages, and by inference the deposits containing them, were assigned to one of the four phases on the basis of the latest group of types they contained. Deposits containing only one or two artifacts could only be slotted into the chronology in more general terms, based on a *terminus post quem* derived from the order of ceramic-type introductions.

Two additional lines of evidence were used in constructing the chronology. An extensive program of crossmending or refitting of ceramic sherds recovered from different deposits allowed the attribution of sherds to individual vessels. The initial seriation made it possible to determine the phase during which pieces of each reconstructed vessel entered the archaeological record for the first time. This yielded a *terminus post quem* for the deposition of other sherds belonging to that vessel. Otherwise undated deposits that contained sherds from phased vessels were assigned *termini post quem* on that basis. Stratigraphic relationships between seriated and undated deposits supply similar information. In some cases, they also yield a complementary *terminus ante quem*.

The foregoing represents a departure from standard approaches to chronological inference in historical archaeology that are based on *termini post quem* from historically documented beginning manufacturing dates of ceramic types (Noel Hume 1972) and on weighted means of median manufacture dates (South 1977). A seriation-based approach offers finer-grained chronological control than the first of these methods. Unlike the second, it offers immediate insight into the empirical correctness of the results, based on an evaluation of the extent to which the pattern of occurrences in the permuted matrix fits the abstract model on which the method is based. This is not to say that evidence concerning historically documented dates of manufacture has no place in chronological inference, merely that there are better means for building relative chronologies within sites. *Termini post quem*, based on documented manufacture dates, come into their own in anchoring relative chronologies in absolute time.

Absolute temporal boundaries for the four-phase chronology at The Clifts were derived in precisely this fashion. Occupations of the site appears to have begun c. 1670. This date is derived from the fact that the Phase-1 assemblages are dominated by lead-glazed coarse earthenwares manufactured by Morgan Jones, a potter known to have operated a kiln in Westmoreland County as early as 1669 and who left the county in 1681 (Kelso and Chappell 1974). Additional corroboration for the date comes not from ceramics, but from the palisade erected around the principle dwelling during Phase 1. Documents indicate that wealthier planters in Westmoreland and adjacent Northern-Neck counties erected such fortifications around their households during 1675 Indian scare that helped precipitate Bacon's Rebellion in the Virginia Colony (Westmoreland 3:308, Andrews 1959:29, Washburn 1972).

Although Jones' wares continue to show up in assemblages until the end of the occupation, the majority of sherds appearing in Phase-2 and later contexts show signs of depositional recycling. Staffordshire Yellow Slip Earthenware was introduced to the site at the beginning of Phase 2, in the form of cups exhibiting finely combed decoration that, on the basis of documents and kiln excavations, appeared on Staffordshire products in the period from c.1680 to c.1700 (Noel Hume 1972:135, Brown 1979:4,19). Together these observations suggest a Phase 1-Phase 2 boundary at c.1685.

A beginning date of c. 1705 for Phase 3 is suggested by the appearance in its earliest deposits of English stonewares with lustrous brown finishes associated with Burslem and Nottingham. These wares went into manufacture c. 1700 (Noel Hume 1972:114, Mountford 1971). That Phase 3 spanned the first decades of the 18th century is corroborated by the appearance of Rhenish Blue-Gray Stoneware mug sherds in Phase 3 deposits bearing the "AR" cipher of Queen Anne (1702-1714) impressed at the rim.

The arrival of Slipped White Stoneware at the site signals the beginning of Phase 4. The initial date of manufacture for this ware is c. 1715 (Noel Hume 1972:114-115, Mountford 1971). Its first appearance in the Westmoreland County probate inventories dates to 1726 (Westmoreland Inventories 1:44). Sherds of Buckley Earthenware, with its distinctive red and yellow banded body, first appear early in Phase 4, although a similar black-glazed, red-bodied ware (hereafter Black-Glazed Earthenware) is present in Phase 3 deposits. Buckley does not appear on Chesapeake sites until c. 1720 (Noel Hume 1972:133, Miller 1983:91). Finally, the earliest Phase-4 deposits contain sherds of Rhenish Blue-Gray Stoneware mugs bearing the "GR" cipher of King George I or II (1714-1727, 1727-1760) on a central medallion. A c.1720 beginning date for Phase 4 is therefore suggested.

Dating the end of the occupation is a more difficult matter. Among the last ceramic types introduced to the site was Unslipped White Stoneware. The earliest documented date of production for this ware is 1720 (Noel Hume 1972:114). The earliest evidence of its introduction to the Chesapeake is recorded in the recovery of several examples from a dwelling documented to have burned to the ground in 1729. Hence the presence of the ware at The Clifts suggests that the occupation continued at least to c. 1730. Just how much longer it continued is problematic. The absence of molded White Stoneware Plates from the assemblage indicates abandonment had occurred by c. 1740. This is also the dendrochronologically documented date for the construction of Stratford Hall, an event that likely occasioned abandonment of the site, if it was still occupied. I have devoted space to chronological matters for a reason. Fine-grained chronological control is a necessary precondition to documenting the temporal patterns that, as was argued in Chapter 4, are crucial to diagnosing evolutionary processes.

6.3 Changes in Site Layout: Phase 1

This and the following three sections provide a phase-by-phase description of changes in site layout, based on the chronology developed above. The treatment includes the sequence not only of construction and destruction of structures, but also of alterations to interior partitioning within the principal dwelling.

Occupation of the Clifts began with the construction of three structures: The principal dwelling (Structure 1), a quarter (Structure 2), and a small outbuilding (Structure 5) (Figure 6.2). The dwelling originally consisted of a three-unit, rectangular core, with exterior dimensions of 18.5 by 41.0 feet (204K/L, 214B, 373C, 386D, 210F, 215D, 372D, 385K, 209E)[1]. Original appendages were attached to three sides of the core: on the north a 12.5-by-15-foot "back room" (204H/J 231G/H, 208E, 213J/K, 232F/G, 233D/E), on the east gable end a 5.0-by-9.0-foot shed (385N/P/R, 385G/H), and on the south an 8.5 by 9.5-foot porch entry (219D, 371L) (Figure 6.3).

6.3.1 The Dwelling

Clues to the interior arrangement of the core come from several sources: post-hole spacing, post-hole shape and hearth placement. The 41-foot core section of the dwelling consisted of two parts: an eastern 30-foot section framed around 4 transverse

[1] Alphanumeric designations here and in what follows are refer to provenience units. Letter pairs separated by a slash (e.g. A/B) represent post mold and hole combinations. Letter pairs separated by a dash (e.g. A-F) refer to multiple layers in a single feature.

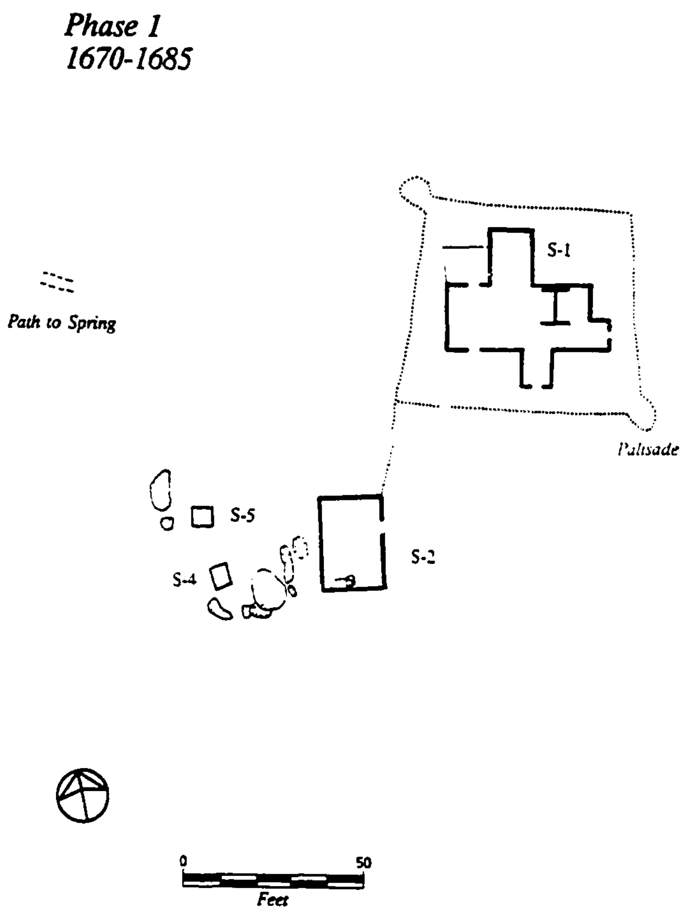


Figure 6.2 Schematic plan of Phase-1 features.

pairs of posts set roughly on 10-foot centers and an 11-foot long western bay. The pairs of posts at each end of the 30-foot section were set in holes .5 feet deeper than the two pairs between them, indicating that this section was a single structural unit. Later repairs during the occupation and previous excavations at the site by amateur archaeologists in 1972 resulted in the destruction of the corner post holes for the western gable end of the house. However, an original post hole at the center of the west gable did survive (209E). This post hole was dug .5 feet shallower than the hole for the center post in the opposite gable (385P). The difference indicates that the 11-foot western bay was not as substantially framed at the 30-foot western section. Two pairs of posts (204C,D and 210G,J) were set in trenches (204E, 210H) opposite one another in the side walls of the 11-foot western bay. The spacing between the posts -- 3.0 feet -- indicates they were door posts. The trenches in which they sat had been dug through the adjacent backfilled holes for the 30-foot eastern section, indicating that it had been erected before work on the western 11-foot bay had begun. As we shall see later in the discussion of plowzone artifact distributions, these technological differences between the western bay and the 30-foot section were mirrored in different flooring treatments, with the western bay receiving an inferior and leaky floor.

The opposed doors of the western bay are the remains of what the English literature on vernacular architecture recognizes as a cross passage. Under the hypotheses concerning room use in three-unit houses discussed in the last chapter, the western bay to which the opposed doors gave access was a service room. The inferior technological treatment of the western bay is compatible with this use. The technological contrasts between the passage-service bay and the rest of the core indicate a partition between

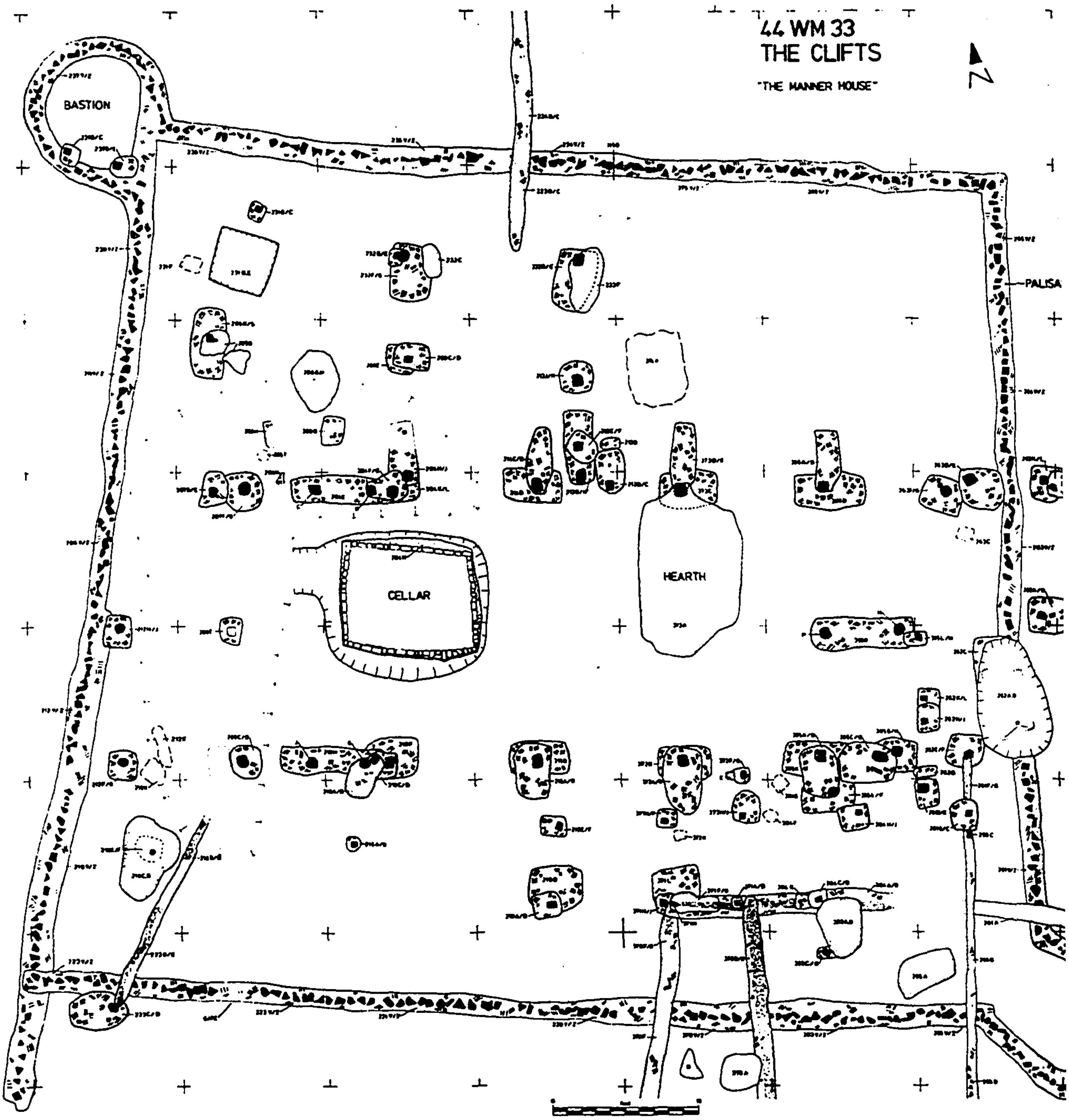


Figure 6.3 Archaeological plan of the principal dwelling (Structure 1) and associated features.

them.

A key feature of the 30-foot eastern section of core was the ephemeral remains of the hearth foundation (373A) straddling the two eastern bays of the core. The feature, a .2-foot deep depression running 10 feet south from the north wall, extended 4 feet into the eastern bay and 3 feet into the western bay where it's original western edge had been truncated by a tire rut associated with recent use of the road that has traversed the site since the 18th century. Its fill, a charcoal-flecked brown loam containing gravel-sized pieces of burned daub and bog iron but no brick or mortar, represents destruction of the hearth, since it partially covered an adjacent wall post to the north (373D). Additional clues to the appearance of the hearth came from the brick-lined cellar, constructed much later in the occupation, just to the west. The cellar had been emptied of its original contents during amateur excavations in 1972. Photos taken then, in conjunction with an examination of sediments with which the cellar was backfilled in 1972, indicate it had originally contained flat bog-iron cobbles that ranged from 1 to 2 feet in diameter and had been burned red on one side. In addition there were large quantities of fire-reddened daub, some pieces of which bore the impressions of woven twigs. The original cellar deposit dated to the destruction of the dwelling and abandonment of the site in the 1730's. It is inferred from these data that the hearth originally consisted of a low platform of bog-iron rubble, laid in clay. The chimney over it was wattle and daub. The hearth foundation accommodated two back-to-back fireplaces, each 4 feet deep, heating a small room on the east and a much larger one on the west. These two rooms, which together with the hearth comprised the 30-foot eastern section of the core, may be labelled "chamber" and "hall" respectively, using 17th-century terminology favored by architectural historians and historical archaeologists (e.g. Upton 1980:175).

Three additional spaces complemented the three units of the core. The diminutive amount of space afforded by the chamber -- a scant 6 feet lay between the edge of the hearth and the gable end of the house -- was supplemented by the 5-by-9 foot shed that projected from the chamber gable. A second appendage was centered on the south side of the house. Similar features in extant houses from the period in both England (e.g. Mercer 1975) and New England (Cummings 1979: 35-36) are porch entries. The use of this feature as an entry for people, affording access to the hall, and as an exit for trash, is confirmed by the evidence from artifact distributions discussed in the next chapter. The third appendage, the back room tacked onto the north side of the dwelling, also led onto the hall.

A final feature of the dwelling requires mention. This was a single post (205R) that lay 10 feet north of the north wall of the core and roughly a foot out of alignment with its west gable end. It was set in a hole similar in shape, size, and depth to those which held the posts for the back room, suggesting a structural role. Its placement out of square with the rest of the dwelling indicate that it supported not a fully framed room, but the outside corner of an open shed, covering the north door to the passage-service bay.

In terms of the classification offered in the previous chapter, the dwelling emerges as a 3/C/ME plan, that is, 3 units, central chimney, entry into the middle and end rooms. Its place in the more traditional categorization of plans is more problematic, a situation that nicely illustrates the inadequacies of that measurement device. The house initially appears to fall into the cross passage with stack away from the passage group (Figure 5.4b). However, the presence of a second entry complicates matters. The traditional classification recognizes only two entry types in central chimney houses: the cross passage and the lobby entry. A close look at the location of the porch entry relative to the hearth indicates that the former did not open onto a lobby entry formed by the side of the fireplace. Instead, the porch gave direct access into the hall. In the traditional categorization, this entry location in only found in the 2-unit, end-chimney plan.

6.3.2 Early Quarter

A second major structure (Structure 2) dated to the initial occupation of the site. The seriation hints that it was constructed earlier than the dwelling (Table 6.2). It was considerably smaller and less elaborate (Figure 6.4). The original quarter was a one-unit structure, 25.2 by 18.4 feet in exterior dimensions and framed around eight posts, seven of which survived (390C/D, E/F, G/H, J/K, A/B, 289AN/AP, 293 C/D). The northeast corner post had been destroyed later in the occupation when the cellar under the second quarter (Structure 3) was constructed. The posts in the west wall were spaced in even modules of 7.5 feet between the four posts. The east wall was laid out in uneven modules of 7.5, 9.0 and 6.0 feet. It is conjectured that the irregularly spaced post (283AN) was a door post. A similar arrangement is found at the contemporaneous John Washington Site, roughly 5 miles up river from The Clifts (Stone 1982:263).

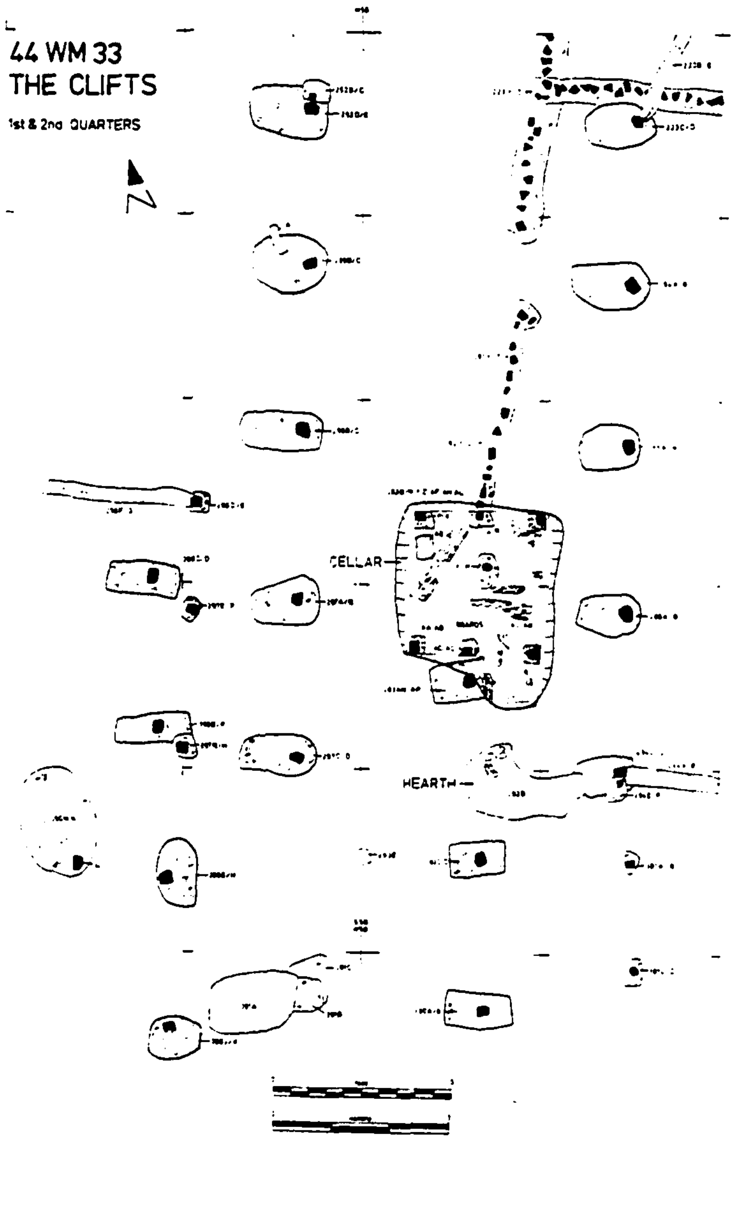


Figure 6.4 Archaeological plan of the original quarter and its replacement.

At the south gable end of the quarter lay a series of three overlapping pits, dish-shaped in profile (391A-C). Their depths below subsoil ranged from .5 to 1.0 feet below subsoil. The fill of the largest (391A) was flecked with charcoal and pieces of fire-reddened displaced subsoil, suggesting a heat source nearby. The pits may represent small root cellars placed adjacent to a gable-end hearth to keep their contents from freezing in winter. Root cellars on colonial Chesapeake sites are usually larger, deeper, rectangular in plan, and wood lined (e.g. Pogue 1988, Kelso 1984). The contrasting size and shape shared by the three pits suggests expedient construction and infrequent use. An alternative interpretation, that the pits were themselves were hearths (Neiman 1980b:82), seems less likely given the absence of any evidence for burning in two of them. While there is evidence that at least some of the rooms of the dwelling were plastered and some of its windows glazed, there are no similar indications for the quarter.

6.3.3 Outbuildings

Roughly 30 feet west of the quarter and aligned with its north gable end was a small, roughly square building (Structure 5), measuring from 5.7 to 5.9 feet on a side (Figure 6.2). It was framed around four posts. The northern pair (319F/G, 319G/H) had been set in holes dug roughly a foot deeper than the southern pair (319A/B, 319C/D), an arrangement that may indicate a shed roof. The remains of this structure shared several characteristics with 5 other buildings (Structures 5-9) erected at different times later during the occupation of the site. All were framed around four posts. They ranged from 5 to 10 feet on a side. Significantly, the post molds of all of them were filled with ash-rich sediments containing large amounts of charcoal, along with gravel to cobblesized pieces of earth that had been burnt red. These shared attributes lead to the tentative identification of all six buildings as smokehouses. The dating evidence for these structures is often not very good. This is to be expected since the buildings were located on the edges of the site, away from areas of high artifact density. In addition, only small amounts of fill were associated with their construction, the contents of the four post holes. These two factors diminished the probability that datable artifacts would be found in their deposits. However, when the evidence from artifacts and from the spatial relationships among these buildings and better dated features is considered, the conclusion emerges that Structures 4-9 were successive replacements for one another. As one burned down, another was erected to replace it. The absolute dearth of artifacts associated with Structure 5 indicates its temporal priority in the series.

Structure 4 (352A/B, C/D, E/F, G/H) measuring roughly 5 by 6 feet in plan and located roughly 10 feet to the south, was its replacement. A variety of artifacts was recovered from its four post holes (n=15). All ceramic sherds mended to vessels that first entered the archaeological record in Phase 1, indicating that construction took place during that period.

6.3.4 Palisade

The most striking feature of the first phase of the occupation was the palisade that surrounded the dwelling. This fence was comprised of split rails set upright and adjacent to one other in a flat-bottomed ditch (220Y/Z, 221Y/Z, 223Y/Z, 218Y/Z, 212Y/Z, 206Y/Z, 211Y/Z, 233Y/Z, 237Y/Z, 236Y/Z, 235Y/Z, 234Y/Z, 375Y/Z, 388Y/Z, 265Y/Z, 264Y/Z, 263Y/Z, 261Y/Z, 273Y/Z, 295Y/Z, 383Y/Z, 370Y/Z). The post molds (Y) left by the split rails could only be distinguished from the surrounding fill (Z) near the bottom of the ditch. As a result, nearly all the artifacts recovered from the palisade were derived from a deposit that was sealed when the palisade was dismantled. The placement of the palisade in the occurrence seriation reflects this event (Table 6.2). The Phase 1 construction date is indicated by the documents discussed above and by the fact that the two sherds recovered from the fill were from Phase-1 types (Morgan Jones, North Devon Gravel Tempered). A 3.0-foot gap between adjacent split rails in the south side of the palisade, just opposite the end-room entry to the dwelling betrayed the location of a gate leading into the main enclosure. The palisade ditch extended roughly 8 feet south of the southwest corner of the main enclosure where it stopped, began again after a 4.2 foot gap, and continued to the northeast corner of the quarter. The gap marks the location of a gate leading to an area south of the dwelling and east of the quarter, probably a garden, which was apparently enclosed by a fence that left no archaeological trace.

6.3.5 Pits

The Phase-1 features that remain to be discussed are pits. These features share irregular plans and dish-shaped profiles. They were dug and filled throughout the occupation of the site. They are characteristic of Chesapeake sites like The Clifts lacking the use of brick in fireplaces and chimneys. They are rare or not found at all on sites where brick was employed extensively (e.g. Kelso 1984:81). The contrast indicates their original use as sources of clay for periodic repairs to earthen chimneys. The deposits or layers that fill them may be grouped into four classes, each with an inferred distinctive source and mode of deposition. The first class is composed of brown, organic loam that includes large numbers of small, broken artifacts. These sediments were apparently derived from topsoil around the site and the artifacts in them represent broadcast disposal of refuse in surface middens. Second, there were deposits comprised of a high proportion of ash and charcoal flecks containing burnt artifacts. These were derived directly from fireplace cleanings. In addition, some layers were comprised largely of displaced, artifact-free subsoil. These sediments were removed from a borrow pit, but were later rejected as unsuitable for architectural use. The fourth class of pit deposit was composed of bedded and sorted sediments apparently eroded by rain from the subsoil sides of the pits.

The Phase-1 pits were adjacent to the two early smokehouses (Structures 4 and 5). Four of them, contained sufficiently large artifact samples to be included in the seriation (346A-D, 290A-D, 289A-H, 305A-G), while others (304A-C, 360A, 362A-C, 351B-H, 356A-G) could be assigned to Phase 1 on the grounds that they contained sherds from Phase-1 ceramic types or mends to Phase-1 vessels.

6.4 Phase 2

The overall structure of the site remained unchanged during much of Phase 2 (Figure 6.5). The major alterations, which can be unequivocally assigned to the period, fall under three headings: the palisade, the chamber (east room) of the dwelling, and borrow pits.

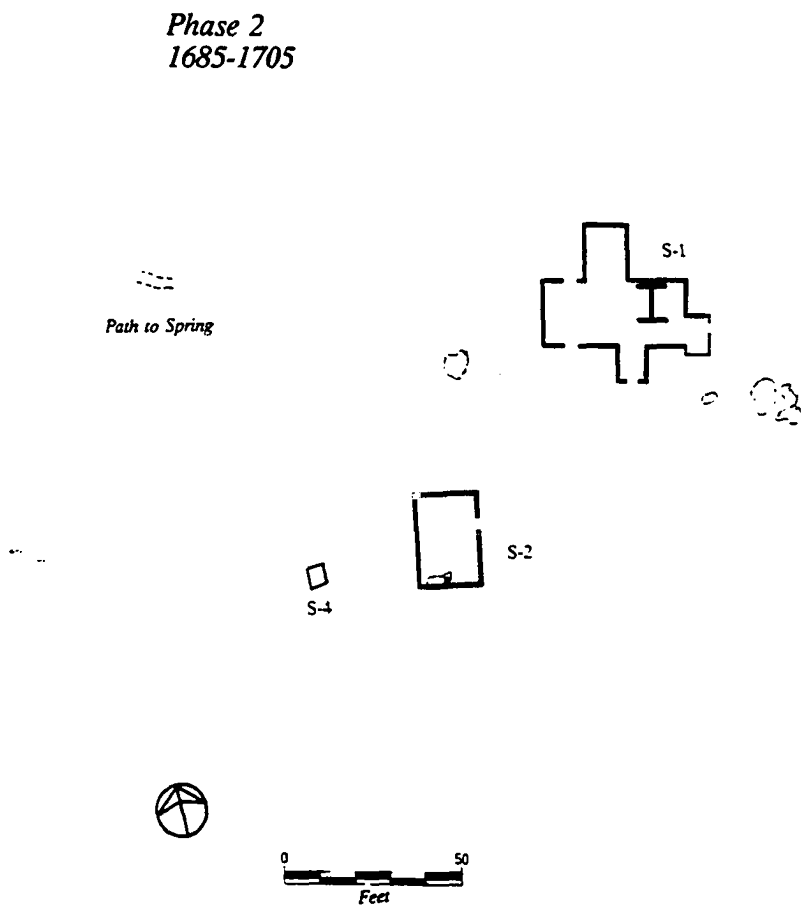


Figure 6.5 Schematic plan of Phase-2 features.

6.4.1 Palisade

As we have seen, the palisade was wholly dismantled during this period. The evidence from artifact distributions to be discussed later indicates that much of the west wall of the fortification had been removed before this. This portion of the palisade was not in place long enough to affect patterns of trash disposal during Phase 1. Its early demise can be attributed to the fact that it would have obstructed access from the dwelling to the site's water source to the west. Both the placement of the palisade in the seriation and the superposition of a Phase-2 pit (273A-C) over a portion of the southeast bastion suggest that the fortification entirely disappeared early in Phase 2.

6.4.2 Dwelling

The small shed or closet protruding from the east gable of the dwelling underwent minor alterations that resulted in the repositioning of its south wall 2.5 feet south of its original location and of the west wall 1.6 feet to the west. Five post holes and molds (385E/F, 261D/E, 262K/L, 262 H/J, 385L/M) were associated with this alteration. Only two ceramic sherds were recovered from them and both could be mended to vessels initially stratified in Phase 2. It is not clear whether these repairs represent a modest addition of living space to the chamber, or whether they merely represent encasement of failing walls in a new shell.

6.4.3 Pits

Five borrow pits date to Phase 2. They were located much closer to the dwelling than their Phase 1 predecessors. Three lay southeast of the dwelling (273A-C, 274A,B, 274E,G). Proximity and similarity in fill of two of these (274A,B, 274E,G) suggest they represent the irregular bottom of a single pit whose upper portions have been plowed away. A forth pit (250D,E) lay just off the southwest corner of the dwelling. According to the seriation it was filled later than the others. The fifth pit (295A), the smallest, contained no datable artifacts. However, the dearth of artifacts suggests it was filled early in the occupation and its proximity to the earlier Phase 2 pits southeast of the dwelling points to a Phase 2 date.

6.5 Rebuilding at the Phase 2-Phase 3 Boundary

While most of Phase 2 was uneventful, the end of the period saw major alterations to the dwelling and replacement of the quarter. The resolution allowed by the occurrence seriation suggests they occurred late in Phase 2, but leaves unresolved the question of whether they represent alterations undertaken during this phase of the occupation, or after its termination but before artifacts dating to Phase 3 were numerous enough on the site to be included in archaeological deposits created at that time. As we shall see later (Section 7.4.1), this ambiguity will be resolved indirectly in favor of the latter alternative. The time at which they occured is therefor referred to as the Phase 2-Phase 3 boundary.

6.5.1 Dwelling

During this period, the dwelling was extensively repaired and the first quarter replaced by an entirely new structure. The post holes associated with the repairs to the dwelling can be assigned to one of 4 structural units. These are represented in the occurrence seriation as Structure 1, Repairs 2-4 (Table 6.2). They can be described as follows. First, the chamber shed, itself repaired early in Phase 2, was demolished and, with the installation of two new gable-corner posts (263D/E, 262E,F), a full 10-foot bay was added to the eastern room of the dwelling. A new shed or closet, carried on a pair of posts (263K/L, 263A/B) 5 feet east of the new gable end, was added in turn to the newly extended chamber.

The second set of repairs involved replacement of two sets of three posts in the north (386A/B, 373D/E, 214C/D) and south (385A/B, 372A/B, 215A/B) side walls on either side of the hearth. The posts in both the northern and southern triplets are linked by several characteristics. Their depths match. Their elongated holes share a major-axis orientation perpendicular to the ridge of the dwelling. The sides of the holes are vertical at their dwelling-side ends, against which the posts are set, while the opposite sides slope gently inward. The repairs represent the replacement of only the rotted bottoms of the original wall posts, leaving their tops and the walls that they carried in place.

The third set of alterations involved the western bay of the dwelling. The posts carrying the western end of the 30-foot eastern section of the dwelling were replaced. The two repairs (204F/G, 210C/D) exhibited none of the characteristics of the triplets to the west, suggesting they were installed without the constraints imposed by the need to incorporate the repairs into preexisting walls. The original gable-end posts were removed and replaced with a pair of new corner posts (209C/D, 207F/G) placed 1.0 foot east of the their predecessors. As a result the western bay of the dwelling shrank from 11.0 to 10.0 feet in length. The opposed pairs of door posts, which had given access to the western bay, were removed without replacement. One of the empty post molds (210J) was packed with displaced subsoil, presumably derived from digging the adjacent postholes. Taken together, these three sets of repairs represent demolition of the original western bay and its replacement by a slightly shortened version to which direct access from outside the dwelling was impossible. A fourth alteration, the demise of the open shed to the north of the western bay, is implied by these changes.

Finally, the porch entry on the south of the dwelling was rebuilt. The twin posts supporting its southern gable were replaced (219A/B, 371H/J). In addition, a post was installed along each of the side walls (219E/F, 371N/P), 4.9 feet from the south end of the porch.

6.5.2 Second Quarter

The original quarter was demolished during this period and replaced by a larger structure (Structure 3), built slightly closer to the principal dwelling. The new quarter had a two-unit plan 19.0 by 36 feet in exterior dimensions. Its side walls were carried by 5 posts, spaced on modules of 9.0 feet (223C/D, 284A/B, 285A/B, 266A/B, 294C/D, 252D/E 299B/C, 298B/C, 297A/B, 297/D) . A shed appendage 14.0 feet long and 6.0 feet wide ran along its west wall (298D/E, 297E/F, 297G/H). Although it is not clear whether the shed was part of the original build, it was standing by Phase 3, when a fence ditch (298F/G) was dug through one of the post holes associated with it.

The new quarter had a cellar beneath it, 7.4 by 7.8 feet in plan, with a 3 foot-long extension in the direction of the southern gable, where the hearth was located. The cellar was 4.0 feet deep. Three post holes were located along the northern (283P/X, Q/R, S/T) and southern (283AA/AB, AC/AD, AJ/AK) side walls, apparently to keep in place a lining of boards wedged between them and the clay walls. A seventh post hole (283V/W) had been dug in the middle of the cellar floor to help support the floor above.

The remains of the hearth of the new quarter, located in its southern gable end, were similar to those in the dwelling. They consisted of a shallow depression, roughly 7 feet across, filled with charcoal-flecked grey-brown loam and a few bog-iron cobbles (293B). The largest layer in the cellar fill (283K) consisted of clay loam mixed with bog iron cobbles up to 2 feet on a side, many of them showing signs of burning. Many of the clay-loam pieces were reddened. Some bore soot deposits on one side and the impressions of riven lath on the other. This evidence suggests the new quarter had a gable-end timber and daub fireplace constructed atop a hearth comprised of bog-iron cobbles laid in clay. Its seven foot width made the quarter hearth 3 feet smaller than the hearth associated with the dwelling. Like its predecessor, the new quarter lacked interior finish, as attested by the dearth of plaster in the layers deposited in the cellar when the structure was destroyed at the end of the occupation of the site.

6.5.3 Outbuildings

Although the dating evidence is equivocal, a new smoke house (Structure 6) may also have been constructed at this time. Like its predecessors, this building was framed around four hole-set posts (364J/K, A/B, L/M, H/E). Exterior dimensions were 5.9 by 6.5 feet. No datable artifacts were retrieved from the building's post holes. However, its location 34 feet west of the second quarter, precisely in line with the quarter's north gable end, suggests it was constructed when the quarter was already standing. A later repair to the east end of this building (364F/G, 364C/D) resulted in an increase in length from 6.5 to 10.0 feet.

6.6 Phase 3

Phase 3 witnessed the installation of an extensive system of ditch-set fencing (Figure 6.6), the construction of two larger outbuildings well south of the previously used area of the site, and the addition of several smaller outbuildings to the western yard.

6.6.1 Ditch-set Fencing

Where the remains of individual uprights of the new fencing system were distinguishable in the fill, they proved to have been split rails. Ditch-set fences enclosed a relatively empty area roughly 200 by 85 feet on the east side of the dwelling, and divided it into four unequal-sized plots. The largest, on the north, was separated from the others by a fence ditch running off the northeast corner of the chamber. In addition, ditch set fences enclosed a yard area or forecourt on to which the dwelling and quarter fronted. Segments of ditch-set fences were also found on the west side of the site. Two of these segments, one south of the new quarter and the other west of the dwelling, had abrupt terminations indicating their use in conjunction with fencing that left no archaeological trace.

During Phase 3 the original ditch-set fence system underwent several minor alterations. The most important of these involved twice moving the fence dividing the forecourt from the garden further east (370D/E; 261F/G,295B). This resulted in the successive expansion of the area comprising the forecourt. In addition, the proportion of

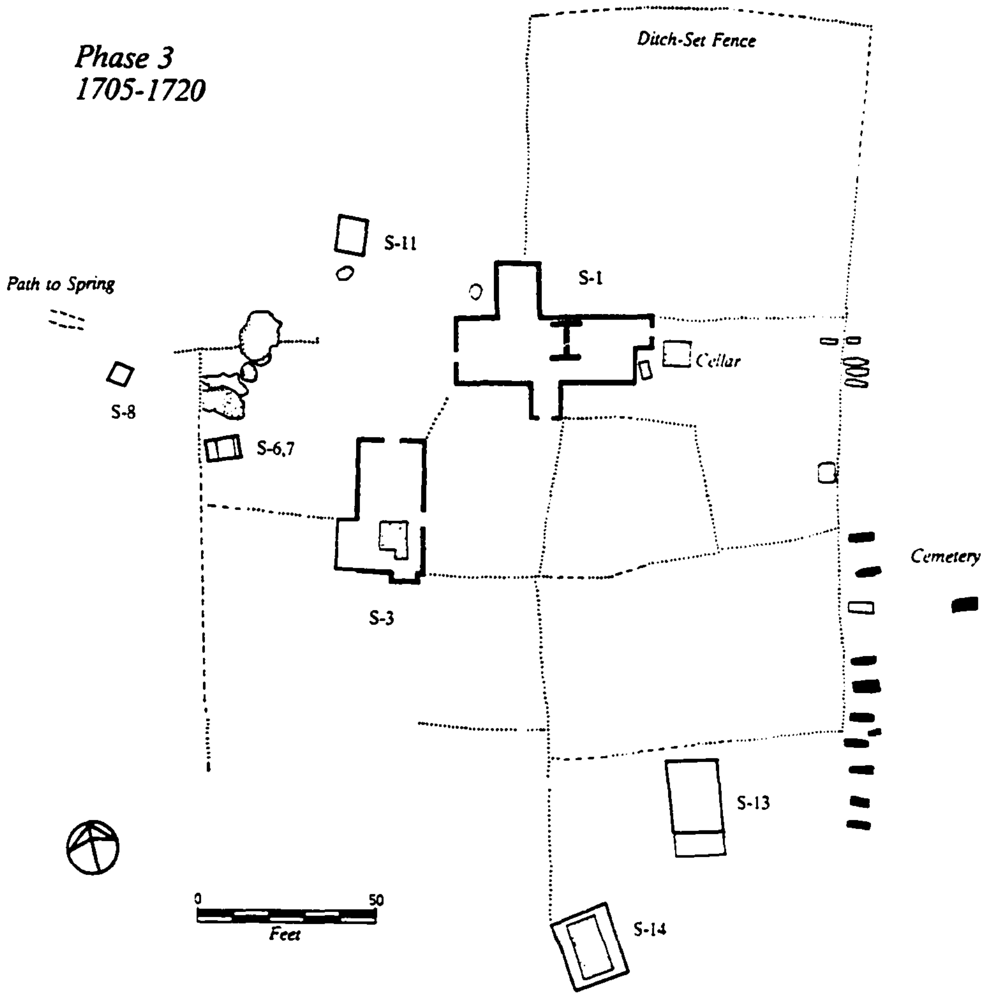


Figure 6.6 Schematic plan of Phase-3 features.

the enclosure around the western service yard that was comprised of ditch-set fences was also increased. Ditch-set fences were constructed along its southern and western sides.

The seriation (Table 6.2, Fence Ditches), indicates that the construction of the original ditch-set fence system dates to early Phase 3. This is corroborated by stratigraphic evidence. Ditches dating to the initial installation of the fence system (294A/B, 370F/G) were dug through, and thus postdate, the post holes for the new quarter and the repairs to the dwelling porch and chamber closet described above. They also cut through the palisade and Phase-2 pits off the southeast corner of the dwelling. The seriation reveals that the ditch-set fence system marks the earliest appearance of Rhenish Blue-Gray Stoneware in a stratified context at the site. The Rhenish sherds in question, recovered from the fence ditch (370F) running south off the dwelling porch, bore the "AR" cipher mentioned earlier, providing a *terminus post quem* of 1702 for the system.

6.6.2 Larger Outbuildings

The ditch-set fence system provides important indirect evidence to date structures whose placement in areas of low artifact density caused a dearth of datable artifacts in the features associated with their construction. A case in point is Structure 13. This building lay just south of the southern end of the fenced garden, roughly 100 feet south of the dwelling. Framed around three transverse pairs of posts set on 10-foot bays (340K, L/M, R/S, A/B, Z/Y, X), its core measured 20 by 15.1 feet in plan. A 6.0-foot deep shed, carried on a trench-laid sill (342A) spanned the southern gable. The building stood long enough to require repairs to its northwest and southeast corner posts

(340 H/J,V/W) and an ancillary support along its west wall (340 AG/AH). Four small, shallow, and irregularly spaced postholes were found along the building's west side. These may have held the ends of props laid against the west side wall to prevent outward collapse (Carson et al. 1981:194, Stone 1982:273-274).

Dating this building is a challenge. Its position just outside the southern edge of the fenced garden suggests that both the fence and the structure stood at the same time. The only chronologically sensitive artifacts recovered from the holes of the structure were two 5/64th-inch bore diameter pipestems (Harrington 1954). This, in conjunction with the empirical frequency distribution of bore diameters across the four phases, suggests that the building was constructed no earlier than Phase 3, when 5/64th-inch pipestems comprise 68% of the pipestem assemblages. A scant 5% of the pipes from Phase-2 assemblages have 5/64th-inch bore diameters. A Phase-3 construction date is therefore indicated. That it was necessary to repair the building indicates, in the absence of any other evidence for the date of its destruction, that it stood for several decades, perhaps to the end of the occupation.

A second two-bay structure was located about 27 feet to the southwest. Structure 14's exterior dimensions were 16.6 by 20.3 feet. It was framed around six posts of which four (366A/B, C/D, E/F, G/H) were uncovered during the excavation. The building had a large cellar beneath measuring roughly 16 by 9 feet in plan and 4.5 feet deep (below subsoil). The cellar originally had a wooden lining supported by posts set in its corners.

Here again dating construction is problematic since no datable artifacts, save sherds of Morgan Jones, were forthcoming from the posthole fill. The building clearly predates the Phase-3 fence ditch (401A) that cuts its northwest corner posthole. This fence ditch segment postdates the original ditch-set garden enclosure. It is tempting to conclude that the the structure was built during Phase 3, sometime after initial construction of the ditch-set fence system, at which time the new fence-ditch segment (401A) was extended to meet it. The building was clearly standing when the Phase-4 post-and-rail system was built (see below). The assemblage derived from the fill (365A-H) in the cellar beneath it is included in the seriation. It too dates this deposit to Phase 4. The fact that the majority of the cellar fill was comprised of water-laid sediments eroded from its subsoil side walls indicates the structure had been dismantled when the cellar was filled.

6.6.3 Smaller Outbuildings

Phase 3 also saw additional structures constructed in the yard to the west of the dwelling. The most substantial of these was Structure 11, an 8.3-by-10.0 foot building situated about 30 feet northwest of the dwelling's west gable. It was framed around four posts set in holes whose size matched the postholes of the dwelling and quarter (239C/D, G/H, 240D/E, H/J). A sherd of Rhenish Blue-Gray Stoneware from a tree hole (239F) cut by one of its postholes (239C/D) places construction during or after Phase 3. The building clearly predates the Phase-4 post-and-rail fence, two of whose postholes (238F/G, 240B/C) intrude the postholes carrying the building's eastern side. The horizontal relationship between the building and a Phase-3 ditch segment, which dates to the original construction of the ditch-set fence system, suggests an origin early in Phase 3. The eastern termination of the ditch segment lies 25 feet south of the building and is precisely aligned with its western wall line. The alignment suggests the ditch was dug when the building was already standing. A small pit (239B) sealed the northwest corner post mold and its hole, suggesting the building was destroyed before the site was abandoned.

Phase 3 also witnessed continuing replacement of the smokehouses in the western yard. Structure 6's successor, Structure 7, was built on the same spot. This four-post building (363J/K, A/B, G/H, M/L) measured roughly 6.5 by 6.0 feet. There were two repairs to the east end (363C/D, E/F). No artifacts were forthcoming from the post holes. Hence its placement in the chronology rests on stratigraphic grounds. A third smokehouse, Structure 8, appears roughly contemporary. Four unrepaired post holes (344 J/K, L/M, N/P, Q/R) supported a structure roughly 5 by 6 feet in plan, situated just beyond the west edge of the yard enclosure. A table glass fragment from one of the postholes (344R) indicates construction during or after Phase 3, given the rarity of table glass on the site during earlier phases.

6.6.4 Dwelling and Exterior Cellars

Four minor, isolated repairs were made to the dwelling during this period. Three of them appear to date early in the period. None contain Phase-3 ceramic types, but all post-date Phase 2 repairs based on stratigraphic evidence. They were located in different positions in the dwelling, one in the rebuilt western bay along the southern wall (210A/B), the other in the east side wall of the back room, where it intersected the core of the dwelling (213E/F), and the third adjacent to the northeast corner post of the chamber. The former two holes were oriented on a diagonal to the structure walls and both are situated within a foot or two of existing posts, characteristics that indicate the posts that they contained were slid into position to support wall plates failing at the juncture with the nearby posts. The third repair post (263F/G) had been installed slightly out of the wall line. A cross section revealed not only that the hole had been dug through the adjacent Phase-2 corner post, but that the post it contained was canted to the east, and thus served as a brace for its neighbor. The fourth repair (208C/D) resulted in the replacement of the intermediate post in the west wall of the back room. A sherd of Colono ware removed from its fill mended to sherds found in deposits assigned to Phase 3 by the seriation.

The most significant changes associated with the dwelling during this period were the construction of two exterior cellars just to the east of the chamber. The remains of the smaller of the two consisted of an oval pit, roughly 8 by 5 in plan and 1.8 feet. deep (262A,B). Four dimple-like depressions, arranged at the corners of a 2.5-by-4 foot rectangle, had been dug at the intersection of the pit's sloping sides and flat bottom (262D), apparently to accommodate the corners of a wooden box inserted into the pit as a lining. The bottom layer of the pit consisted of displaced subsoil, fill from behind the lining that collapsed into the pit when the lining was removed. The cellar had been dug through the corner post installed as part of the Phase-2 renovations and therefore postdates them. It did not last long; the seriation places its fill in early Phase 3.

Although there is no direct evidence, the larger cellar located adjacent to it may have been dug at this time as a replacement. It measured 8.1 by 8.8 feet in plan and was

2.0 feet deep. Removal of the fill (269A-F) revealed a packed clay floor. The larger cellar was filled at the end of the occupation (Table 6.2).

6.6.5 Pits

Several borrow pits of varying sizes were dug and filled during Phase 3, most of them clustered just at the edge of the western yard. Four contained sufficiently large artifact samples to be included in the seriation (255F-Y, 240F-G, 288S-AD, 255A-E). Others could be assigned to the period on the grounds that they contained Phase-3, but not Phase-4, ceramic types or contained sherds that mended to vessels whose earliest stratified appearance was in Phase-3 deposits (259A-D, 205G-M, 226B, 288C-R). The last of these, had been largely emptied of its original contents during the 1972 amateur excavations The largest of the Phase-3 pits (255A-E) had been dug through two earlier deposits (255F-Y, 255Z-AH) destroying all but a small portion of the latter. A single pit (309A) had been dug on the opposite side of the site, just within the east boundary of the ditch-set garden fence.

6.7 Phase 4

The last phase of the occupation witnessed the construction of a new fence system and several outbuildings in the west yard (Figure 6.7). In addition, renovations were undertaken at the dwelling.

6.7.1 Post-and-Rail Fences

The ditch-set fence system was replaced entirely by fencing carried by hole-set posts on 10-foot centers. To the east of the dwelling, the earlier multiple enclosures gave

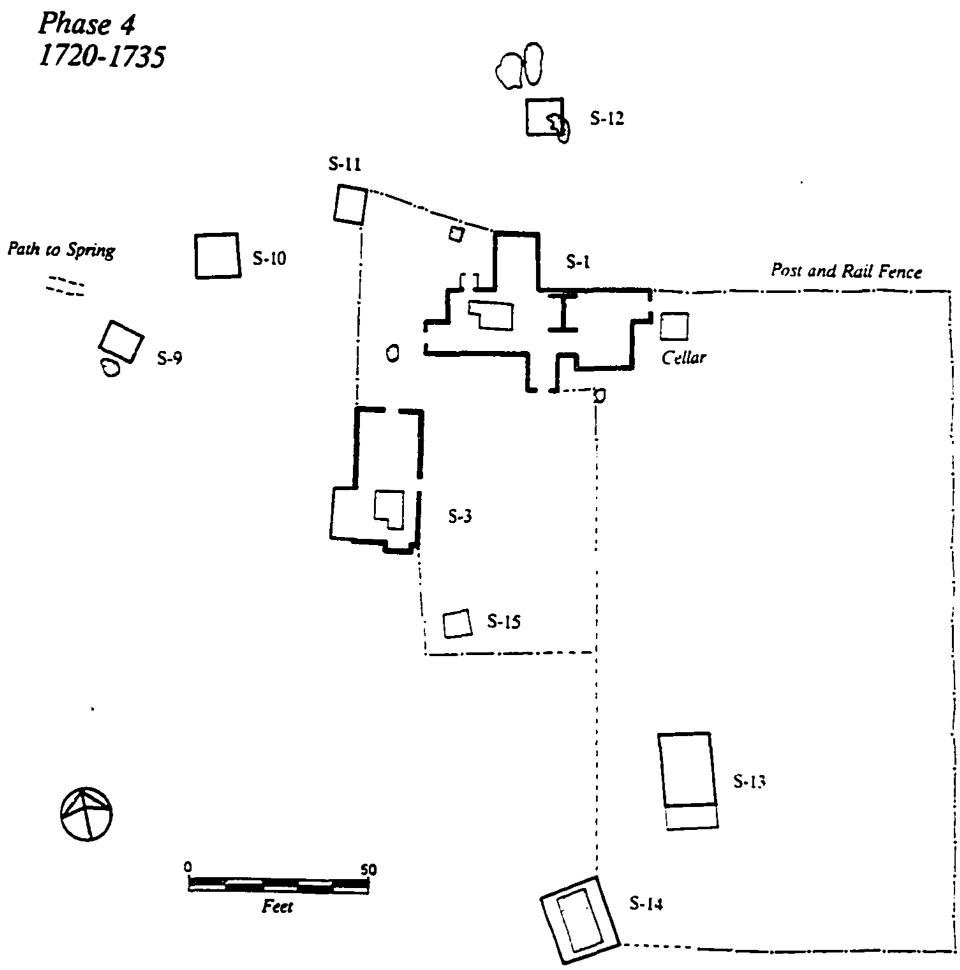


Figure 6.7 Schematic plan of Phase-4 features.

way to a single rectangular area clear of interior divisions. The new garden enclosure was 100 feet across and extended roughly 180 feet south of the dwelling. Structure 14 was apparently incorporated into the enclosure at its southwest corner. On the opposite side of the dwelling, the new post and rail fence enclosed a small area at whose corners stood the back room of the dwelling, Structure 11, and the quarter. It also incorporated the yard area south of the dwelling and east of the quarter.

The Phase-4 date of construction for the post-and-rail fence system derived from the occurrence seriation is backed up by stratigraphic evidence. Its post holes intrude but are never intruded by features dated to Phase 3 on other grounds (e.g. Structure 11, the ditch-set fence system). However, the relationship between it and Structure 14 provides the single discordance between the order of deposits inferred from the seriation and from stratigraphic evidence. The garden enclosure was planned so that Structure 14, which had already been built, lay at its southeast corner. The seriation places the destruction of Structure 14, signalled by the erosional filling of its cellar, just prior to the construction of the post-and-rail fence system, reversing their correct relationship.

6.7.2Outbuildings

Three new outbuildings were constructed in the west yard. One of them, Structure 9, was a smokehouse built on the same spot as Structure 8 and, on those grounds, clearly a replacement for it. Like all of its predecessors, Structure 9 was framed around 4 posts (343A/B, C/D, E/F, G/H). Its exterior dimensions of 8.5 by 10.0 feet were roughly double the size of its predecessors'. The Phase-4 date is inferred from the recovery from one of its post holes (343E) of a Staffordshire Yellow Slip Earthenware cup whose other sherds were found exclusively in Phase-4 contexts.

Another large, 4-post outbuilding was situated between the new smokehouse and Structure 11. Structure 10 was roughly 12 feet square. One of its original four post holes (257C, D/E, F/G, H/J) had been repaired once (257A/B). A 4/64-inch bore diameter pipestem recovered from a posthole (257E) provides the evidence that the building dates to late Phase 3 or Phase 4. At the Clifts, pipestems of this bore diameter occur in Phase-4 deposits with one exception: a late Phase 3 pit (255A-E).

A third outbuilding, Structure 12, was constructed roughly 40 feet north of the dwelling. Framed around four post holes (378A/B, C/D, J/M, G/H), it was square in plan, with side walls 10.0 to 10.5 feet in length. Stratigraphic and artifactual evidence agree on the Phase-4 construction date. Two of the building's postholes (378C/D, G/H) intruded the west boundary ditch for the Phase-3 fence system (277D/E, 377A/B). The fill of one of its post holes contained a sherd of a tin-glazed bowl the rest of which was found stratified in other Phase-4 contexts.

The last phase of the occupation also witnessed the construction of Structure 15 in the southwest corner of the fenced yard between the dwelling and quarter. In relation to the other four-post structures described above, its post holes and the molds they contained were diminutive (320A/B, C/D, E/F, G/H) and its side walls, ranging from 6.2 to 7.8 feet in length, were out of square. Destruction during Phase 4 is indicated by a sherd of White Stoneware recovered from a post mold. Given the slight scantling of the posts (roughly 0.3 feet on a side) and the irregular plan, the building's construction could not have been much earlier.

6.7.3 Dwelling

Repairs and alterations to the dwelling during this period were more extensive than during Phase 3. The western end of the building received the bulk of the renovations. Chief among these was the installation of a small brick-lined cellar beneath the western room or hall. Its interior dimensions, at the bottom of its sloping walls, were 6.0 by 7.8 feet. The earthen floor lay 4.4 feet below subsoil. The cellar was emptied of its original contents during the amateur excavations of 1972. Snapshots of the fill in section taken at the time, the only documentation, show that plaster and bog-iron cobbles were important constituents, indicating the cellar was filled when the dwelling was torn down. The dating evidence for its construction is derived from a single sherd of a tin-glazed plate recovered from the builder's trench (204N), part of a matched set of plates and ba' ıs whose fragments occurred exclusively in Phase-4 deposits.

At the time the cellar was installed, the west gable end of the dwelling was rebuilt two feet west of the previous exterior wall line. Only one of the two new corner postholes (207D/E) survived the 1972 excavations. A 6-by-9.3 foot closet or porch, carried on two posts (212F/G, H/J), was added to the new gable end. All three post holes contained unmortared brick bats, presumably construction debris from the cellar. Here again further evidence for the Phase-4 date comes from crossmends between sherds recovered from them and vessels that were first stratified on the site in Phase 4.

The presence of unmortared brick provides the only dating evidence for a pair of postholes (208H, 208G) dug roughly 4 feet apart and 4 feet north of the hall. The 1972 excavations had destroyed their molds and much of the holes themselves. Installation of these posts may mark the opening of a doorway in the north wall of the hall.

Possibly related to the new door was a roughly 3-foot square, 1-foot deep pit just 11 feet north of the hall. Although its side walls were eroded, the pit fill (231D/E) contained no eroded subsoil, indicating the pit was emptied of wash layers while in use. The pit was not aligned with the dwelling but with the Phase-4 post-and-rail fence segment running between the corner of the back room and Structure 11. This suggests the pit post dates the fence. The seriation places filling of the pit at the end of the occupation. A sanguine interpretation is that the pit was a privy to which the door offered access from the hall.

The east side of the dwelling was also altered. A 3.5 by 15.8 foot shed, carried on three posts (261B/C, 384H/J, 372H/J) was added to the south side of the chamber. One of the holes (261C) had been dug through a late Phase-3 fence ditch (261F/G). A second (384J) contained sherds of vessels first stratified in Phase-4 pits. Associated with this change were two additional post holes. a small posthole (372F/G) was dug at the intersection of the west wall of the shed and the south wall of the dwelling. A much larger post (385C/D) was installed in the wall line.

A final alteration to the dwelling before its demolition at the end of the occupation was the removal of the back room. This is attested by a small pit (233F), filled in Phase 4, that had been dug through the northeast corner posthole and mold (233D/E).

6.7.4 Pits

Three Phase-4 pits contained sufficiently large numbers of artifacts to be included in the seriation. Two of them (277A-C, 280A-H) were located just north of Structure 12. The earlier of the two (277A-C), like the adjacent outbuilding, had been dug through the Phase-3 garden fence ditch. The third seriated pit was located on the western edge of the site, next to the the latest and largest smokehouse. The remaining Phase-4 pits were assigned to the phase on the basis of vessel crossmends. One of these (378 E,F,K) was located beneath Structure 11 and was apparently dug while the building was still standing -- the southeast corner postmold was visible from the top of the pit, but the pit had been dug through the posthole. The others were scattered closer to the dwelling (218C,D, 233F, 383A,B).

6.8 Cemetery

A final aspect of the site layout that requires description is the cemetery. Seventeen discrete grave shafts were located along the east edge of the Phase-3 garden and an eighteenth was found 30 feet to the east (Figure 6.7). The shafts were clustered in two spatially discrete groups: a north group comprised 5 closely spaced shafts and a south group whose members were considerably more spread out. Two of the shafts in the south group (332A and 336A) contained no skeletal remains. The diminutive size of the former indicated its occupant had been an infant whose remains had totally decayed. The latter, an adult-size shaft, had been dug into an earlier interment (337A) and apparently abandoned as a burial. A second burial in the south group (328B,C) had also been intruded by an uncompleted shaft (328A).

All five individuals in the north group were white, while all but one of the individuals in the south group were black (Angel 1980). Dating the interments is of obvious relevance to documenting any shift in the racial composition of the labor force at The Clifts. Basic demographic data and dating evidence for the burials are summarized in Table 6.3. Two children (321A,B 322A,B) in the north group --apparent siblings (Angel 1980)-- date to Phases 1 or 2 on stratigraphic grounds. One shaft is located inside the Phase-3 fence ditch, while the other is cut by it. Two north-group white adults can be assigned to Phase 4. One shaft (323A,B) intruded the Phase-3 fence ditch, while the other (325A,B) yielded a sherd of White Stoneware. The fifth north-group burial contained no datable artifacts.

Table 6.3 Basic demographic data and chronology for Clifts burials (Angel 1980).

PROV.	AGE	SEX	RACE	PHASE
NORTH GROUP				
321	5	M	W	1-2
322	4	F	W	1-2
323	31	M	W	4
324	37	F	W	?
325	32	M	W	4
SOUTH GROUP				
326	22	M	B	4
327	43	M	B	3-4
328	31	M	W	?
329	18	F	B	?
330	39	M	B	3-4
331	30	M	B	3-4
333	27	M	B	3-4
334	22	M	B	3-4
335	10	M	B	3-4
337	26	F	B	3-4
338	58	F	B	4

Eight of the eleven south-group burials contained datable artifacts. All 8 can be assigned to the second half of the occupation. The occurrence of 5/64th-inch pipestems in the fill of 4 burials (331A,B, 333A,B, 334A,B, 337A,B) points to their being Phase 3 or 4 interments (see above). Inclusion of Staffordshire Brown Stoneware in the fill of another burial (327A,B) leads to a similar conclusion. A sixth burial (338A,B) can be assigned to early Phase 4. A sherd of white saltglaze stoneware was included in its fill and the burial was intruded by a posthole associated with the Phase-4 post-and-rail fence. Crossmends yielded *termini post quem* for the other two datable north-group burials. A fragment from a North Devon Gravel-Tempered pot, the rest of which was found in Phase-3 deposits, places the burial (330A,B) in the second half of the occupation. A sherd from a Rhenish Brown Stoneware bottle placed the other (326A,B) in Phase 4 on similar grounds. This leaves two black burials (329A,B, 335A,B) and the lone white burial (328B,C) in the south group undated.

Even with the chronological lacunae, it is evident that the second half of the occupation saw a dramatic increase, perhaps from zero, in the number of black slaves living and dying at The Clifts. The inference is that prior to this time the labor force was largely composed of white indentured servants who, having survived their periods of service, left the plantation to die and be buried elsewhere.

6.9 Behavioral Inferences from Architectural Variation

Alterations to an existing structure at The Clifts mirror change in the repertoire of plan types found in newly constructed houses at the close of the century. The dwelling at the Clifts was originally built with a three-unit plan. By the beginning of Phase 3, the opposed doors that gave access to the third room had been blocked and the half-unit space of the third room had been incorporated into the hall. As we have seen, half-unit spaces and three-units plans also disappeared from the region-wide sample of houses at the end of the century. Thereafter the modal plan type in the region was characterized by two-units, with direct entry into one of them, and end fireplaces. The alterations at the Clifts left the dwelling with the now popular direct entry into one of two ground-floor rooms, although the dwelling retained its central fireplace. It is this parallel with deterministic sorting of house-plan variants at the regional level that makes The Clifts relevant to the investigation of the winnowing process.

So far the systematic examination of the behavioral significance of architectural variation has been limited to the rectangular core of dwellings. As the foregoing description makes plain, data from The Clifts provide a complete picture of alterations to the entire dwelling and to the layout of the site as a whole. They therefore offer the opportunity to explore in greater detail patterns in the arrangement and use of space within the dwelling and surrounding structures, and the relationships among them. The functional-morphological arguments of the previous chapter (Section 5.4.6) can be used to infer something about the character of behavioral variants that were sorted along with archaeologically documented architectural variants at the site.

Recall our expectation that early Chesapeake sites should be divided between a centrally located general-activity area and peripheral special-activity areas largely devoted to bulk processing and storage. The size of the latter should be a function of the scale of activities -- the bulk of items processed and/or the refuse generated. The distance of special-activity areas from general-activity areas should scale inversely with access frequency, that is the number of times during the day individuals must travel from one to the other.

I have already suggested how English three-unit plans are partitioned among general and special activity areas. In its Phase-1 incarnation, The Clifts dwelling, with its three-unit, end and middle-room entry, and center-chimney plan is a case in point. The hall and diminutive chamber, both apparently heated by substantial back-to-back fireplaces, may be seen as a general-activity area, partitioned between a large space devoted to food preparation and consumption and socializing, and a smaller one for sleeping. The western service room was a special-activity area presumably for bulk-processing tasks of relatively small scale and short duration. The opposed doors offered easy access to it from yard areas on either side of the house. The area covered by the shed on the north side of the service room was used in a similar fashion.

Moving out from the dwelling, we encounter the early quarter (Structure 2). A central question is the extent to which the early quarter served as a separate general-activity space, devoted to laborer food preparation and consumption, sleeping, and socializing, or was simply a special activity area for larger scale bulk processing and/or storage than was possible in the western room of the dwelling or the adjacent open shed. The quarter's expediently dug root cellars, with their hint of a nearby, ephemeral hearth suggest that the early quarter saw some use for small-scale food storage, preparation, and consumption and was therefore infrequently used as a general-activity area. On the other hand, the heating and cooking facilities found in the dwelling were far more substantial, a contrast compatible with a much lower frequency of such behaviors in the quarter. Although ambiguity must be acknowledged, the architectural evidence is compatible with the notion that the quarter was for the most part a bulk-processing and storage facility and only infrequently used as a general-activity area.

The last of the three buildings dating to the beginning of the occupation was Structure 5. Its small size suggests it housed the processing of low-bulk items, generating little refuse. Hence its spatial segregation must have been a function of long processing times. Distance from the dwelling suggests low access frequency. This building's usage as a smokehouse has been inferred on the basis of its destruction by fire. The congruence between this inference and those derived from functional-morphological arguments provides additional support for the approach.

The basic structure of the site remained intact during Phase 1 and much of Phase 2. However, by the beginning of Phase 3 major changes in the arrangement and use of space had occurred. The demise of the western half-unit room of the dwelling room and open shed to the north of it indicates the end of the usage of that segment of the dwelling as a special-activity area. In addition, the eastern room or chamber nearly doubled in size, raising the possibility that it had become the site of additional activities.

Phase 3 witnessed construction for the first time of a single-bay outbuilding (Structure 11) that lacked the evidence of burning that would have identified it as a smokehouse. By Phase 4 it had been joined by 2 more single-bay buildings with uncharred posts (Structures 10 and 12). That these buildings were not smokehouses is further suggested by their shared larger size (c. 100 square feet) and location closer to the dwelling than the other special-activity structures erected during Phases 3 and 4. This suggests similarity in activity scale and access frequency among them, relative to other structures, and hence perhaps similarity of activities. They share their size and relative proximity to the dwelling with the disused half-unit western room of the dwelling, indicating that these structures may have housed activities that had been carried out in the western room during Phases 1 and 2.

The second quarter (Structure 3) was erected at the same time the western room of the dwelling disappeared. Three characteristics are noteworthy: its two-unit plan, a substantial end fireplace, and a well-constructed root cellar beneath the heated room. All three made the new quarter resemble the dwelling more than its predecessor had. The fireplace was as well constructed as that in the dwelling. With the cellar, the new quarter acquired an underground storage facility to match those installed in the garden just outside the dwelling at about this time. The fireplace and cellar imply an increase in intensity of food preparation, consumption, and storage for this structure relative to its predecessor. The use of the unheated room is less clear. However, these attributes imply the second quarter was a more frequently used general-activity area, on a par with the dwelling.

Phase 3 also saw the construction of the twin two-bay buildings (Structures 13 and 14) in the south end of the garden. Their size and distance from the dwelling indicate they housed large-scale bulk processing with low access frequency relative to the other special-activity structures. The cellar beneath one of them is the largest underground storage facility on the site. If the early quarter was the site of large-scale bulk processing during Phases 1 and 2, such activities may have been removed to these buildings during the second half of the occupation.

To sum up then, three major trends can be inferred to have occurred in the arrangement and use of architectural space at The Clifts: the removal of small-scale bulk processing from the dwelling to smaller outbuildings, the appearance of a second general-activity area with heating and cellar facilities to match those of the dwelling, and the removal of large-scale bulk processing and/or storage from the quarter to dedicated structures. All three of these developments occurred late in Phase 2 or early in Phase 3. In the next chapter I marshall evidence from the horizontal distribution of artifacts in plowzone across the site to evaluate these behavioral inferences.

Chapter 7

Assemblage Variation in Space and Time

7 Introduction

This chapter attempts two things. The first is to evaluate the extent to which inferences about changes in the use of space at The Clifts, based on architectural variation, hold up in the light of inferences derived from an independent source: variation in the distributions of different ceramic types across the site. As we saw in the previous chapter, if there is agreement, then one of the two hypotheses for the processes behind deterministic sorting of house plans may be correct. If there is no agreement, neither hypothesis is likely to be correct and there would be little point in undertaking the second goal of the chapter: to determine whether the economic or discrepancy hypothesis better accounts for changes in the arrangement and use of architectural space at The Clifts.

7.1 Studying Spatial Variation

In the previous chapter, I suggested that the architectural alterations that occurred at the Phase 2-Phase 3 boundary were accompanied by changes along three dimensions of behavioral variation. The first of these was the removal of some bulk-processing and storage activities from the dwelling to outbuildings. The second was the appearance on the site of two general-activity areas, where previously there had been one. The third was the initiation of near-exclusive use of each of these areas by one of two different social groups: laborers and their owners. Evaluating the extent to which evidence from the horizontal distribution of artifacts in the plowzone across the site supports these inferences is a complex endeavor. What is required is a way to use ceramic evidence to infer the location of bulk processing and storage, to infer the location of food preparation and consumption, and to define the extent to which general-activity areas were shared by the two social groups.

The first two inferences depend upon the existence of predictable relationships between ceramic form and use. Of particular interest is the identification of dimensions of variation in ceramics likely to be associated with bulk processing, cooking, and food consumption respectively. As we have seen, such relationships are established through functional-morphological arguments describing the mechanisms that jointly sort artifactual and behavioral variants. I cannot offer a complete account here. However it is possible to suggest in a tentative way the kinds of uses likely to have been associated with various ceramics recovered. Recent archaeometric work on ceramic performance characteristics offers a plausible starting place. The third inference requires the identification of artifact classes for which frequency of use within the two social groups was characteristically different. Classes which measure stylistic divergence between the cultural repertoires of the two groups would suffice. So too would measures of functional divergence caused by differential access to resources for the two groups. In addition, inferences on all three topics will require functional-morphological arguments concerning the manner in which ceramic artifacts were deposited, in particular the relationship between locations of use and deposition. Unlike the buildings dealt with in the previous chapter, ceramics may be disposed of in places other than those in which they were used.

7.1.1 Behavioral Inferences

Recent experimental studies have demonstrated that temper, nonplastic inclusions that are either added to a ceramic paste during manufacture or naturally present in the clay source, has a predictable effect on the performance characteristics of the resulting vessels. Temper affects several parameters that are likely to constrain, via deterministic sorting, the uses to which vessels are put. The most important of these is vessel strength.

Overall strength of a ceramic vessel may be decomposed into absolute strength, as measured by the force necessary to initiate cracking, and toughness, measured by the force required for complete failure of the ceramic body, once cracking has been initiated (Feathers 1989:587). Absolute strength is inversely related to temper size and density, while toughness scales positively with both. Ceramic bodies lacking temper therefore will fail immediately after crack initiation while those with temper will continue to function. Temper also affects heating effectiveness. Containers made with tempered pastes transfer heat to their contents more quickly than containers without temper (Skibo et al. 1989).

This kind of variation in performance characteristics offers some justification for the notion that deterministic sorting should favor certain kinds of uses for different ceramic wares, on the basis of temper characteristics. When physical shocks are an unavoidable and frequent concomitant of use, tougher vessels with larger amounts of temper should be employed. Bulk processing, in which vessels are subject to relatively large matter-energy flows over extended periods of time, is one such context. Another is cooking. Toughness, conferred on vessels by temper, is at a special premium in cooking vessels. It translates into resistance to crack initiation resulting from thermal shock that necessarily accompanies each episode of use (Feathers 1989, Skibo et al. 1989, Steponaitis 1983:37-45). Since larger amounts of non-plastics also make for more efficient transfer of heat from energy source to vessel contents, cooking vessels are likely to have especially large amounts of temper. Conversely, if ceramic bodies lack non-plastics, the vessels from which are made are unlikely to have been used in activities associated with heat or heavy usage. Vessels used in food consumption -- eating and drinking -- and for short-term food storage fall into this group.

The distinction between coarse and fine earthenware captures this variation in a gross way. Coarse earthenwares are "coarse" precisely because their bodies contain larger amounts of non-plastics. Within this group, wares with larger amounts of temper should be more frequently employed in cooking. There is some independent support for these notions. Shapes, which we know from 17th and 18th-century documents were typically used in the processing and storage of dairy products (e.g. milk pans and butter pots), tend to occur in coarse earthenwares (Beaudry et al. 1983). Also encouraging is the fact that among coarse earthenwares that commonly occur in Chesapeake sites, the most highly tempered (North Devon Gravel-Tempered Earthenware) is the ware that occurs most frequently in vessel shapes associated with cooking in contemporary documents (Watkins 1960). On the other hand, fine earthenwares and stoneware tend to occur in shapes that are associated in contemporary documents with eating and drinking (e.g. plates, cups, mugs, bowls [Beaudry et al. 1983]).

The foregoing considerations, coupled with our earlier discussion of site structure, suggest a possible means by which general and special-activity areas might be identified with the help of ceramics. As we saw in Section 5.4.6, general activity areas should be the site of food consumption and cooking. Hence we can expect them to be characterized by high usage rates for fine earthenwares and stoneware, on the one hand, and very coarse earthenwares on the other. Special-activity areas devoted to bulk processing, should be characterized by high use frequencies for coarse earthenwares.

In addition to sherds derived from vessels, a second group of ceramic artifacts will prove helpful for current purposes: clay pipe fragments. The frequency of smoking in different areas of the site should be a function of the amount of time addicted individuals spent in different areas. By definition, general-activity areas are more frequently used than special-activity areas. In addition, smoking rates would be higher in general activity areas, as a concomitant of social interaction, than in special activity areas where demands of work would render smoking more difficult and hence less frequent per unit time, at least for workers. On both counts the expectation is that general-activity areas should be the location of more smoking and hence generate more smoking-related debris.

The third question on which ceramic evidence must be brought to bear is the extent to which two social groups hypothesized to have coexisted at the site, laborers and owners, used the same spaces as general-activity areas. This will require isolating patterns of spatial variation in artifact classes with different frequencies of use in each group as a result of different histories of stochastic or deterministic sorting. Variability within the group of ceramics suggested to have primarily been used in food consumption emerges as a promising area for investigation. Given the hypothesized mode of use for fine earthenwares and stoneware, deterministic pressures on details of ware and shape variation within this class of ceramics are likely to be either small or directly related to differences in their cost of acquisition. Hence synchronic variation across the site will relate to either stylistic differences between the two groups or functional differences that are directly related to differences in resource access and resulting available energy surpluses (see Section 4.4.1).

Pipestems can be helpful here as well, at least for the early years of the occupation when two different types of pipes were in use. White clay pipes were imported from England; red ones were manufactured of local clays (Henry 1979, Emerson 1988). The disparity in the distances over which they were traded suggests that there were cost differences between them. On these grounds we might expect higher relative frequencies of use of red pipes among laborers as a result of deterministic sorting in the context of restricted resource access.

7.1.2 Formation Processes

Making use of evidence from the plowzone distribution of artifacts also requires positing relationships between locations in which ceramics were used and those in which they were deposited and finally excavated. In other words, we require hypotheses concerning the effects of depositional processes at work on the site during its occupation and of post-occupational alterations in artifact location. At The Clifts, the former were governed largely by the trash-disposal behavior of the site's occupants while the latter were a function of recent agricultural activity.

Positing relationships between location of ceramic use and disposal again requires functional-morphological arguments. And again recent ethno-archaeological work provides a starting point (Binford 1983, 1987, Deal 1985, O'Connell 1987). Two variables appear to control depositional behavior at sites with extended periods of occupation. First, the distance over which sherds are transported from locations of use and failure to separate locations of disposal is a function of the intensity of use of the area in which they were broken. Intensively used areas, areas that will be used repeatedly during the course of an occupation, will be kept clean of refuse, presumably because trash interferes with the conduct of other activities. Second, cleaning up is a function of the interference potential of different artifact classes that in turn scales artifact size, among other variables. The fact that activity areas at The Clifts were housed in or adjacent to permanent structures indicates patterns of recurring use that are associated with cleaning up. Hence we can expect refuse generated within them to have been removed from them. Just how far refuse was removed was a function of the extent to which adjacent outdoor areas were also intensively used areas and this, as we shall see, was variable during the course of the occupation.

In general the foregoing argument leads to the expectation that, over the course of an occupation, concentrations of refuse ("middens") should accumulate on the ground surface just outside the activity areas in which the refuse originated. Going further, when buildings are involved, middens can be expected adjacent to the doors from which their refuse was tossed. When structures have multiple rooms and multiple entries, middens should accumulate outside each entry and their contents should be derived from the rooms adjacent to the closest door. As we shall see, the distributional evidence from The Clifts does offer a partial fit to this model: middens do tend to occur at the locations of doors whose presence is known on independent grounds. Indeed, this model has been the silent premise lurking behind studies of plowzone artifact distributions at several sites in the Chesapeake, beginning with Keeler's pioneering efforts more than a decade ago (Keeler 1978, Neiman 1980a, Miller 1983, King and Miller 1987, King 1988, Pogue 1988).

However, depositional processes were clearly more complex than the traditional picture suggests. Evidence for this comes from a comprehensive program of refitting of ceramic sherds recovered from plowzone at The Clifts. Although the details lie beyond the scope of this chapter, the results can be summarized briefly. Sherds that mend to one another, and hence originally belonged to the same vessel, are on occasion confined to a single midden area. More often, however, sherds from the same vessel occur in different middens. Often these are middens adjacent to different structures. In addition, sherds from the same vessel show up not only in midden areas but in non-midden areas as well. These data indicate that the simple picture often invoked, in which vessels were broken and their sherds cleaned up and immediately dumped out the nearest door, needs revision.

Although the details of the depositional process are still unclear, the implication is unavoidable that cleaning up a single failed vessel took place in multiple episodes.

Three possible aspects of the process are worth explicit mention. First, when vessels were broken only the largest sherds were disposed of immediately, while the remaining pieces might be left lying in place or temporarily placed in corners until they were removed during later partial cleanups. The fact that sherds were allowed to remain on the floors of structures after the initial failure of vessels from which they were derived raises the possibility that when structures have leaky floors, middens will occur not only adjacent to them but beneath them as well. Second, large sherds of some broken vessels, especially large vessels, might be recycled to be used in ways and locations different from the parent vessel. Finally, when disposal did occur, whether immediate or delayed, sherds might discarded anywhere in the site, although there were clearly statistical preferences for areas closer to the location of cleanup. In other words, the total area which might receive artifacts from a given activity area was much larger than the relatively small, high-density midden area adjacent to it. That most sherds recovered from plowzone come from low-density, non-midden areas is a reflection of this fact.

An additional factor complicates this picture. As we saw in the last chapter, pits were regularly dug throughout the course of the occupation to obtain clay for architectural repairs. The resulting empty holes were often filled with refuse-rich sediments. Such episodes of filling represent a disruption in the ongoing processes of refuse disposal described above. The filling of pits removes their potential to interfere with ongoing activity performance. Hence a pit may attract refuse and/or refuse-laden sediments from areas on the site distant from it (e.g. Deal 1985). The spatial location of artifacts in pits therefore may be more a product of the location of the pit than the location of the artifacts' final failure.

This portrayal of ceramic depositional processes has several implications for making inferences about activity locations. Inferences about the frequency of use of a given artifact class in one area of the site relative to another needs to be based on the distribution of sherds over the entire site. The important measure in such comparisons is the mass of the concentrations associated with different structures, where mass is the product of density and spatial extent. Mass can be readily appreciated on maps of densities of single artifact classes. A similar point applies to inferences based on the relative frequency of use of two or more artifact classes in different areas. Because the actual depositional area associated with a given activity area is likely to be considerably larger than the "midden" adjacent to it, estimates of relative frequency for a suite of artifact types associated with that area should be a function of the values encountered not only in the midden, but also in the surrounding region of the site. Just how big this region should be is a function of the spatial scale of the depositional processes operating at the site.

Note how the underlying learning rules posited in the foregoing arguments are similar to those invoked in our earlier discussion of site structure. In both cases the energy expended in the removal of phenomena (objects and processes) from a given location is a function of their interference potential. It is likely that behavioral flexibility in both cases may be governed by the same set of learning rules.

A final topic deserves brief mention: plowing. The Clifts Site lay in a field which had been under continuous mechanized cultivation since the 1930's and under animal and human-powered cultivation since the abandonment of the site. Hence the question arises to what extent patterns in the distribution of artifacts across the site might be referable to plowing as opposed to the behavior of the site's occupants. The effects of plowing relevant in the current context are the distance over which, and direction in which, artifacts are displaced from their original locations. Several recent experimental studies have suggested that mean distance of displacement on each plow pass is on the order of three feet (1 meter)(Lewarch and O'Brien 1981). Displacement is almost twice as great in the direction of plowing than perpendicular to it (Odell and Cowan 1987). The field in which The Clifts was situated was plowed in a north-south direction. Hence if plowing has had important effects on the pattern of artifact distributions, it should be manifest in the tendency for the major axis of artifact concentrations to run north-south. For some artifact classes and some concentrations this is the case. However, the existence of many artifact concentrations for which it is not the case suggests that distorting effects of this kind are minimal.

If plowing does not affect horizonal distributions in important ways, this is not true for vertical ones. Plowing, often in concert with the effects of erosion, will bring to the surface artifacts originally stratified in subsurface pits. When, as is often the case, the features whose upper layers are disturbed by the plow are artifact rich, the plowzone over them becomes a high-density area. It is important to distinguish such areas from the artifact concentrations discussed at the beginning of this section. The location of artifact clusters plowed from pits is a function of the location of a hole that needed to be filled, while the location of midden-derived concentrations is a function of ongoing trash disposal from the buildings with which they were associated.

7.1.3 Mapping Methods

The plowzone covering the core of The Clifts site was excavated by hand and screened through quarter-inch mesh to insure uniform artifact recovery. Of the 128 excavation units, 116 were 10-foot square quadrats. The remainder were 5-by-10 (7), 5-by-5 (2), 7-by-10 (2), and 7-by-5 (1) on a side. The arrangement of quadrats across the site leaves something to be desired for current purposes. Areas to the south, east, and west of the two quarters (Structures 2 and 3) are particularly poorly sampled, although coverage is good to the north of these structures and beneath them. This gap in knowledge of the site detracts from the confidence that can be placed in conclusions concerning differences between the dwelling and quarter in absolute use frequencies of a given artifact class and is a major weakness in this study. The possibility that these unsampled areas contained middens cannot be discounted entirely. In what follows, I make the assumption that concentrations in these areas were negligible. Note, however, that inferences based on patterns in relative artifact frequency do not share this defect.

All maps of the distribution of single artifact types were prepared as follows. Raw quadrat counts were converted to densities per 100 square feet of plowzone. The densities were assigned to site grid coordinates of the center of each quadrat. Density values were interpolated on a regular grid between the quadrat centers using a surface spline algorithm (SAS Institute 1985a:413-424)). Surface splines are functions of the original data points, chosen so that they pass through those points and maximize an objective measure of smoothness that represents the amount of curvature in the spline surface in both grid directions. The only inflections in the surface are those required to honor the original data points (Meinguet 1979).

The interpolated surface was then contoured. Contour intervals were based on quantiles of original frequency distribution of raw quadrat counts. The quantiles employed are called letter values (Tukey 1977). Successive contour lines represent the quadrat count values found at the lower 1/4, the 1/2 (the median), the upper 1/4, 1/8, 1/16, 1/32, 1/64, and 1/128 of the frequency distribution of the mapped artifact class. This technique of interval selection guarantees that the three-dimensional surface is faithfully rendered in areas of higher density while offering a common probabilistic yardstick with which to make comparisons among artifact classes with wildly different frequency distributions. A quadrat density at a given letter value is half as likely to result from random sampling as a density at the letter value just below it.

The foregoing discussion has made liberal use of the notion of middens. Letter values provide a simple way to define just what a midden is. In what follows, middens will be considered artifact clusters whose density equals or exceeds the upper 1/8 quantile of the frequency distribution for that class. This definition is inevitably arbitrary but has the virtue of consistency across artifact classes. On the maps of artifact densities to follow, contour intervals representing lower densities are represented by dashed lines, while the higher densities are represented by solid lines. The first solid line in the series represents the upper 1/8 quantile, the midden threshold value. The locations of quadrat centers are shown on the maps as points.

7.2 Phase 1 and 2 Ceramic Distributions in Plowzone

With the necessary preliminaries now sketched in, it is possible to turn to the description of patterns in the distribution of ceramics across the site dating from the first half of the occupation. To do this we require artifact classes the majority of whose members were deposited during Phases 1 and 2. Here complications arise. For some ceramic ware classes in use throughout the occupation it is impossible to distinguish which sherds date to Phases 1 and 2 and which date to Phases 3 and 4. For example, an exhaustive program of crossmending and a subsequent site-wide minimum vessel count (see below) established that of the 38 North Devon Gravel-Tempered Earthenware vessels represented in the total site assemblage, 3 were initially stratified in Phase 1, 10 in Phase 2, 9 in Phase 3, and 16 in Phase 4. Unfortunately current techniques do not allow the reliable discrimination of which plowzone sherds belong to which vessels. Nor is there any means of discriminating early from late North Devon sherds in the aggregate. The vessel count suggests that a plowzone sherd map for the ware will for the most part reflect later deposition. The ceramics that can be used to examine the use of space during the early phases of occupation are therefore a subset of those actually in use on the site.

The datable ceramic types for the first half of the occupation include a single representative of the three major ware categories discussed above: coarse earthenware, fine earthenware, and stoneware. These are respectively: locally manufactured Morgan Jones Earthenware, Staffordshire Yellow Slip Earthenware, and Rhenish Brown Stoneware. Although white clay pipes were used throughout the course of the occupation, chronologically earlier pipestems can be distinguished by their larger bore diameters (Harrington 1954). Among white-clay pipestems those with 9/64, 8/64 and 7/64-inch bore diameters appear to date to the first half of the occupation. So too do red-clay pipe fragments. Spatial pattern in the distribution of each is described below.

7.2.1 Patterns in Absolute Frequency

The distribution of Morgan Jones Earthenware is shown in Figure 7.1. Most of the sherds mapped here are derived from utility vessels: milk pans (8), butter pots (4), and pitchers (4), although small cups (5) are represented as well[2]. This ware was the predominant coarse earthenware at the site during Phase 1 but stratigraphic evidence suggests a few pieces were still in use during Phase 2. Hence spatial patterning offers a means to measure the location of bulk-processing during the first half of the occupation.

Four large concentrations are evident. The first is associated with the quarter (Structure 2) and partially extends under it. It has two smaller concentrations within it. One is located at what post-hole spacing suggests was the entry for the structure. The other is situated at the opening in the fence running from the palisade to the quarter. The arguments of the previous section indicate the contents of this midden are for the most part derived from the quarter. The second major concentration is found roughly 20 feet northwest of the west end of the dwelling, while the third lies about 40 feet west of it. Proximity to the dwelling suggests it was the source of at least the former. Note,

---

[2] Numbers in parentheses here and in what follows denote the minimum number of vessels represented in stratified deposits sealed during the time period in question, here Phases 1 and 2.

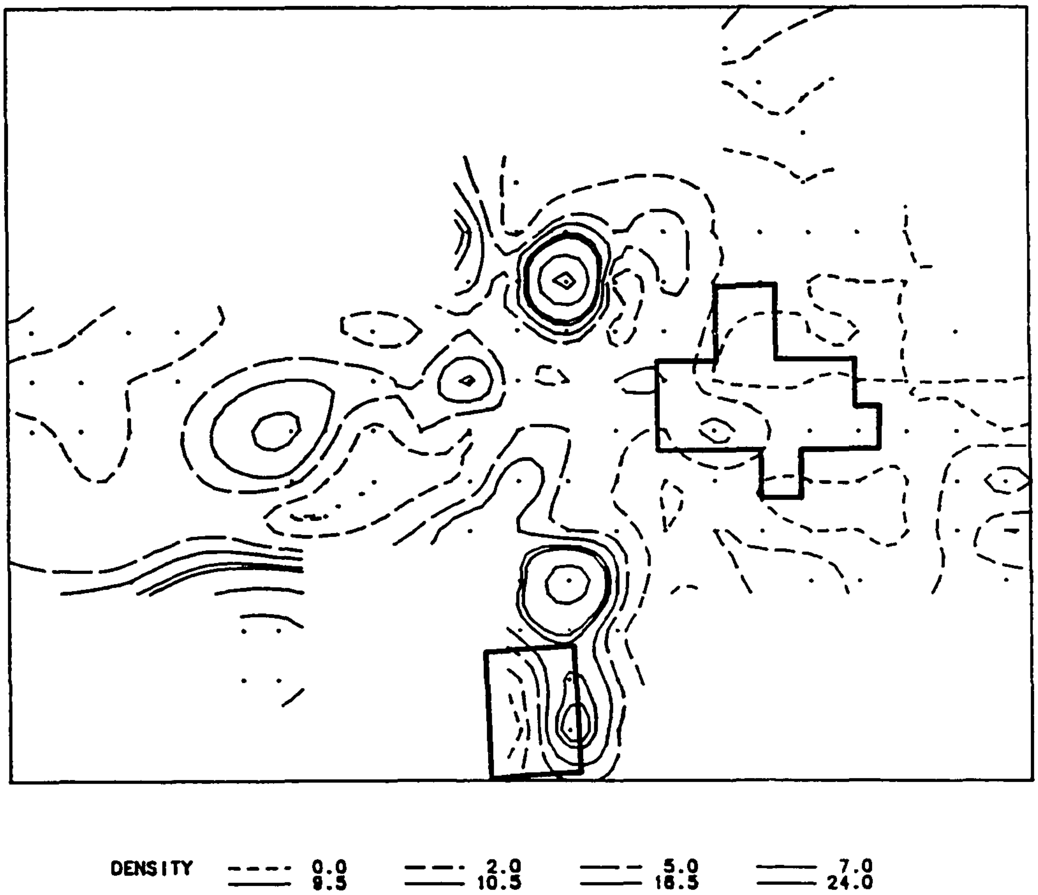


Figure 7.1 Plowzone distribution of Morgan Jones Coarse Earthenware.

however, that this midden occurs some distance from the dwelling, but the midden associated with the quarter is adjacent to it. The contrast indicates that the area north and west of the dwelling was an activity area that was kept clean. Some support for this notion comes from the existence of the open shed on the north side of the dwelling's western bay. The fourth major concentration is centered on four isolated quadrats 50 feet west of the quarter. While the first three concentrations are surface middens, the fourth is entirely the result of artifacts being plowed from Phase-1 pits beneath the four quadrats.

The pattern described above, in conjunction with earlier arguments, indicates that bulk processing was associated with both the quarter and the western end of the dwelling. In addition there is some indication that these activities were confined to the interior of the quarter, but may have taken place both inside and just outside the west end of the dwelling. The larger mass of the quarter midden suggests it was more frequently used for such purposes.

As suggested earlier, clay pipestems should provide some insight into overall use frequencies of different areas. Harrington's results indicate that 9 and 8/64th-inch bore diameter white pipes are the earliest on the site. Their distribution is shown in Figure 7.2. Four high-density areas emerge. Two of them are the results of artifacts plowed from pits: a large concentration west of the quarter and a smaller one off the southeast corner of the dwelling overlie Phase-1 and Phase-2 pit clusters respectively. The difference in size of the concentrations indicates that most of the 9 and 8/64th-inch pipes were deposited during Phase 1. Of the remaining two middens, the larger is situated off the southwest corner of the dwelling but extends under the western room, an indication of a leaky floor. The smaller is located at the gate in the fence between the southwest corner of the palisade and the quarter. The locations and disparity in size of these two middens suggest higher frequencies of smoking associated with the dwelling than with the quarter.

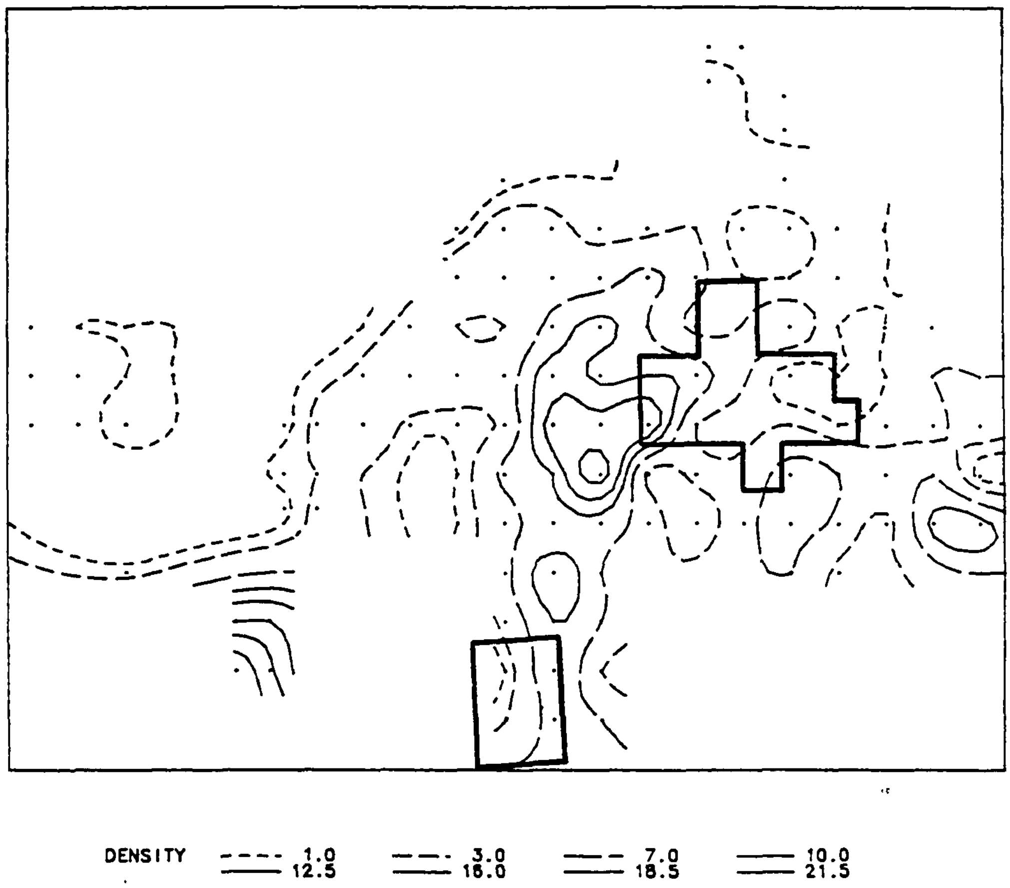


Figure 7.2 Plowzone distribution of 8 an 9/64th-inch pipestems.

The distribution of 7/64th-inch white pipes is shown in Figure 7.3. Both similarities and contrasts with the map of 8 and 9/64th-inch pipes are evident. Note first confirmation of the hypothesis that 7/64th-inch pipes were deposited later on average than the 8 and 9/64th-inch pipes. The plowzone concentration of 7/64th-inch pipes over the Phase-2 pit cluster southeast of the dwelling is larger than the concentration over the Phase-1 pit cluster west of the quarter, reversing the relationship found with 9 and

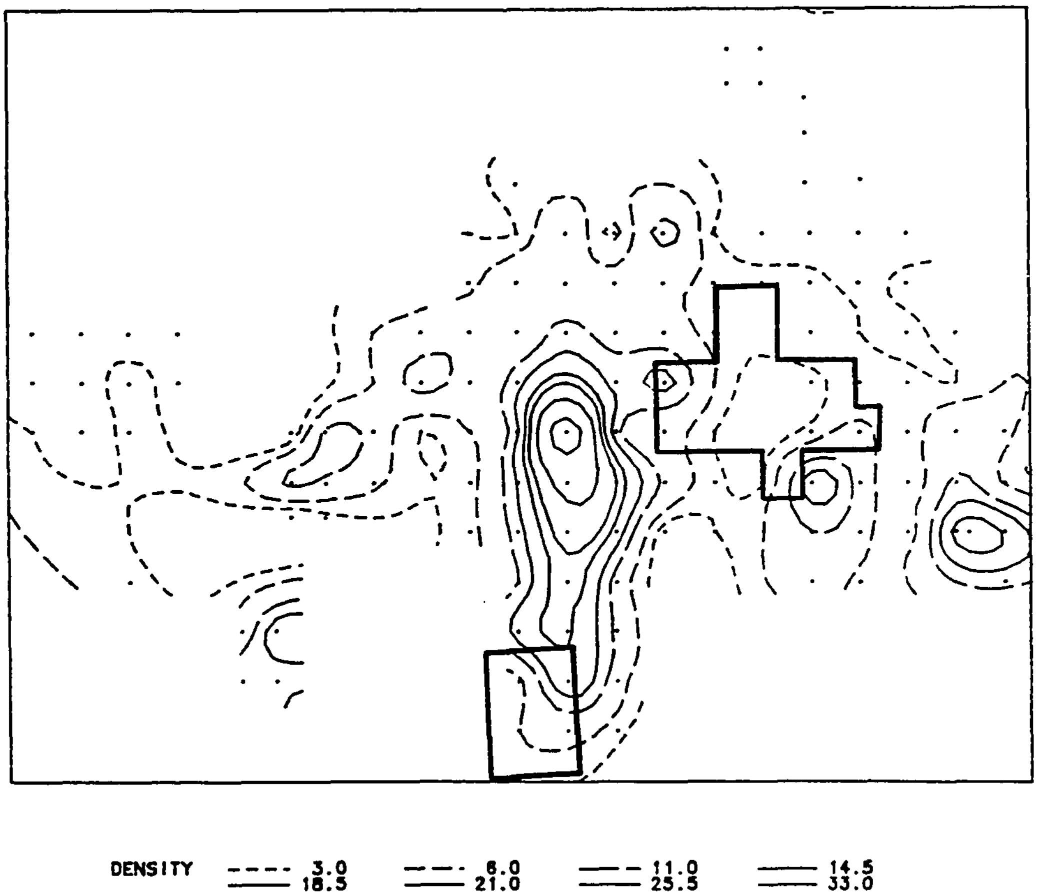


Figure 7.3 Plowzone distribution of 7/64th-inch bore diameter pipestems.

8/64th-inch pipes. There is a small midden beneath the western room and adjacent to the porch entry of the dwelling. The major midden stretches between the dwelling and quarter. There is a bulge in its eastern edge in the direction of the south entry to the western room. The midden lacks separate peaks attributable to each structure. On the premise, suggested by our earlier arguments on disposal processes, that pipestems originated in the structure to which they are closest, smoking frequency during Phase 2 was higher in the dwelling than in the quarter. However the differential was not as great as it had been in Phase 1.

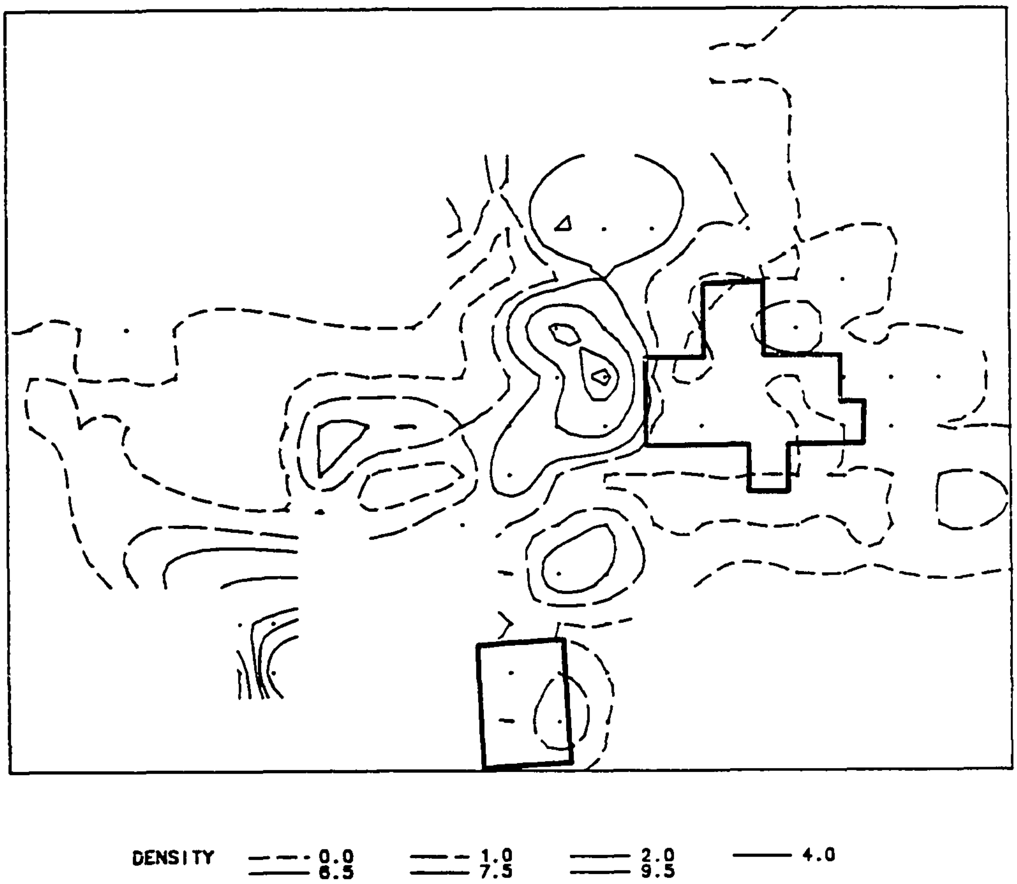


Figure 7.4 Plowzone distribution of red-clay pipestems.

Stratified deposits reveal that red-clay pipestems were only in use at The Clifts during Phase 1. In general their spatial distribution resembles that of the early white-clay pipes, with concentrations over the Phase-1 pit cluster, at the gate near the quarter, and adjacent to the west end of the dwelling (Figure 7.4). As was the case for white-clay stems, the dwelling midden is far larger than the quarter one. However, the white and red-clay pipe concentrations next to the dwelling are spatially complementary. While the white-clay pipe concentration is situated off the dwelling's southwest corner, the red-clay pipe concentration is located off its northwest corner. Note that the red-clay midden is located in the same general area as the concentration of Morgan Jones coarse earthenware associated with the dwelling.

If red-clay and white-clay pipes can be associated with laborers and owners respectively, these data indicate that the dwelling was the primary activity area for both groups, but that their usage of its spaces differed in such a way as to lead to complementarity of refuse disposal patterns. One possibility, consonant with previous evidence, is that labcrers used the western room and the shed north of it more frequently, while owners used the middle room, the hall, more frequently.

Sherds of Staffordshire Yellow Slip Earthenware deposited during the first half of the occupation can be distinguished by finely combed decoration, a decorative technique that only occurs on vessels initially stratified in Phase-2 contexts. The vessels from which they are derived are small cups. Two major concentrations are evident (Figure 7.5). One of them, southeast of the dwelling is the result of plowing from Phase 2 pits. The second is located off the southwest corner of the dwelling, suggesting they share an origin with the white-clay pipes found in the same area.

The distribution of Rhenish Brown Stoneware is far more noisy (Figure 7.6). Three vessels are represented by the mapped sherds, one of them initially stratified

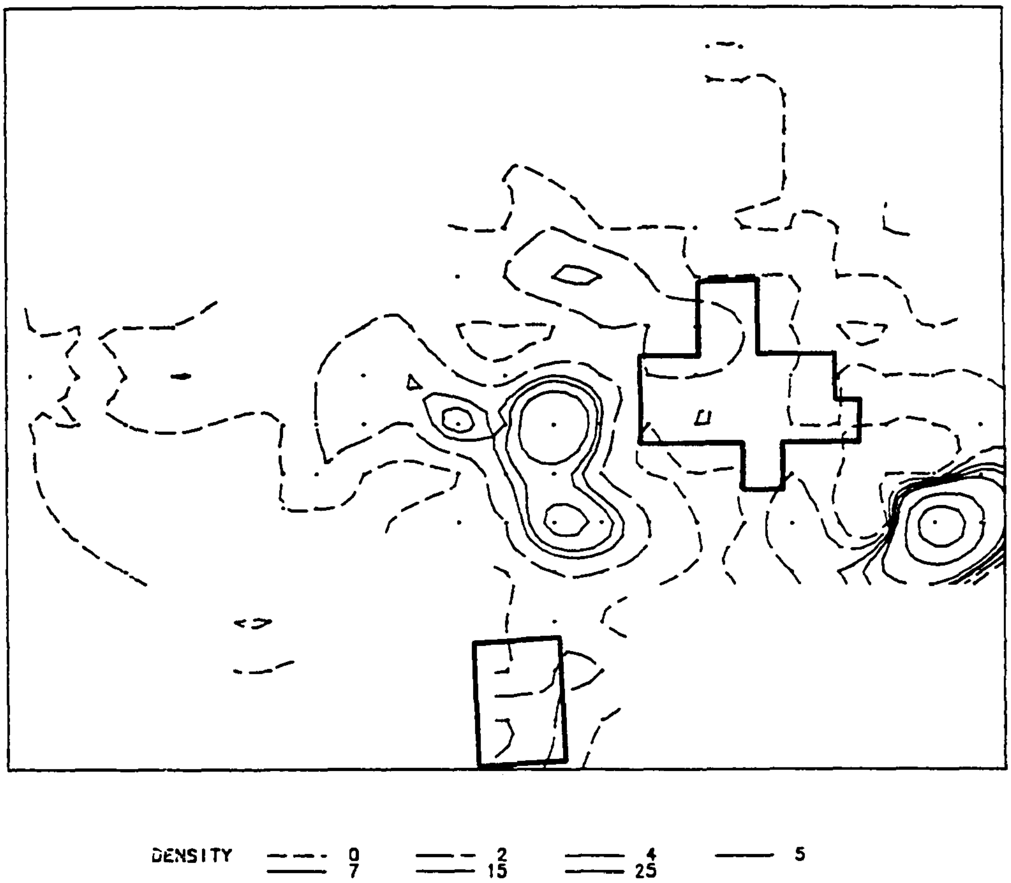


Figure 7.5 Plowzone distribution of Staffordshire Yellow Slip Earthenware from Phase 2.

during Phase 1, the others during Phase 2. All three are large bottles. Several sherd clusters can be distinguished around the dwelling. Three of them in places we have encountered before: off the southwest and northwest corners and over the Phase-2 pit clusters. There is another small concentration just east of the east room of the dwelling.

This examination of the location of plowzone artifact concentrations indicates that the majority of refuse on the site was being generated by the western half of the dwelling. Discounting the concentration caused by plowing from the Phase-2 pit cluster, the eastern half of the dwelling generated little refuse and appears therefore to have been infrequently used. Only in the case of Morgan Jones is a large midden associated with the quarter. This suggests the quarter was largely a bulk-processing area and infrequently used as a food preparation, consumption, and living space. The western end of the dwelling was a less frequently used site of bulk processing. The dwelling emerges as the primary general-activity area on the site.

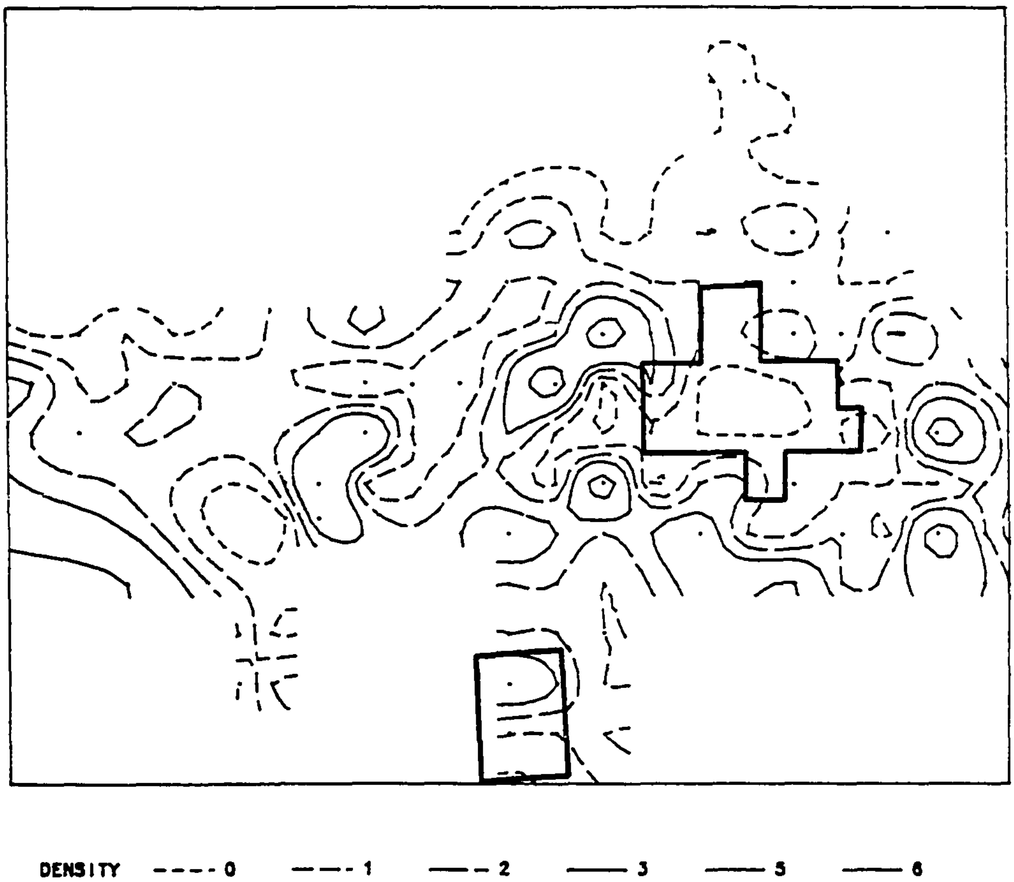


Figure 7.6 Plowzone distribution of Rhenish Brown Stoneware from Phases 1 and 2.

7.2.2 Patterns of Relative Frequency: Smoothing

So far we have looked at patterns of absolute frequency in single artifacts. As was mentioned earlier, the resulting inferences suffer from the possibility that major middens lie outside limits of plowzone excavation. This is one motivation for supplementing the above discussion with an examination of patterning in relative artifact frequencies. Conclusions based on relative frequencies are less affected by the possibility of missed middens. However, there is a second motivation that derives from the earlier observations about refuse disposal processes: large numbers of artifacts lie in non-midden areas. So far these have been ignored. Differences in their relative frequency from one area of the site to another should be related in a systematic way to patterns in the relative frequency of task performance and resulting refuse disposal. On the one hand, low-frequency patterning should remain in areas in which ceramics fail and from which they are subsequently incompletely cleaned. On the other, areas into which refuse was infrequently thrown should retain the signature of its origin. Hence we can expect that variation in artifact frequency across the site will be resolvable into a set of zones each of which includes not only high-density areas of deposition, but also contiguous low-density areas of deposition and use.

A set of techniques is required by which these zones can be resolved. One problem that needs to be confronted in devising such techniques lies in the fact that estimates of relative frequency of different ceramic types in low density areas will be enormously affected by sampling error arising from the small number of disposal episodes. One way around this is to attempt to attempt to smooth away random fluctuations in the raw artifact counts before computing and analyzing relative frequencies (e.g. Johnson 1984, Whallon 1984). A weighted moving average is a simple way of doing this. To compute it we need to decide on the amount of space over which averaging will take place and the appropriate weighting scheme to use within the area averaged over. These issues are of more than technical interest since too much smoothing will destroy spatial patterning (Rogers 1982), yet too little will allow random variation to obscure it.

Consider the first issue: the distance over which the moving average should be applied. It should be clear from our earlier discussion of formation processes that an artifact actually recovered from one quadrat might have been recovered in a nearby quadrat, given a different realization of the stochastic depositional and post-depositional processes involved. Thus the distance over which the moving average is taken should be chosen so as to include quadrats close enough to a given quadrat that artifacts that in fact were deposited in the latter might, on other realizations, have ended up in the former. On the other hand, it should exclude quadrats so far away that the artifacts in them are unlikely to have been deposited in the quadrat for which a smoothed value is desired. What is required then is an estimate of the distance over which quadrat counts are statistically independent of one another or, equivalently, the size of the dominant scale of spatial clustering in the artifact surface. Such an estimate can be had by examining the manner in which, over the entire site, similarity in counts between pairs of quadrats falls off as the distance between them increases. In other words, we are interested in spatial autocorrelation of the artifact density surface.

A simple way to measure the tendency for counts in adjacent quadrats to be similar is to compute the root mean-squared difference between counts in all pairs of quadrats on the site that are a given distance apart. This distance may be referred to as a spatial lag. The measure of similarity is called the semivariance. Computing the semivariance for successively greater spatial lags and plotting the resulting values against those lags yields the variogram, a picture of the way in which the difference between quadrat counts falls off as a function of the distance between the quadrats. Typically the resulting variogram is an upward sloping line that flattens out as distance increases. The distance at which this flattening or "sill" occurs provides the desired estimate of the scale of spatial clustering (Davis 1986:239-243, Burrough 1983). This suggests the general scale of distance or range past which the weights of the moving average should take on 0 values.

The second issue is the weighting scheme to be used within the range. In computing a smoothed artifact count for a given quadrat, how much weight should be assigned to nearby quadrats? There are two options: either weight all quadrats equally or give a higher weight to quadrats closer to the quadrat for which the smoothed estimate is desired. The latter approach seems more reasonable given the earlier discussion of formation processes. The chance a given artifact might have found its way to one quadrat and not another should fall off as a function of the distance between the two quadrats. So too should the influence of nearby quadrats on the smoothed estimate. A simple way to accommodate this feature is to compute the smoothed estimates with a weighted moving average in which the weight assigned a quadrat declines as a function of the distance between it and the quadrat location for which the smoothed estimate is desired.

There are several ways in which the foregoing reasoning might be translated into an equation for the smoothed estimate $\hat{y}_i$ for a given quadrat. Among the simplest is to make the quadrat weights a linear function of distance from the point to be estimated, with a slope of -1/r, where r is the range, the spatial lag at which the variogram flattens out. The smoothing equation then becomes:

$$\hat{y}_i = \Sigma_{j=1}^{n} (y_j w_{ij}) / \Sigma_{j=1}^{n} w_{ij} \qquad (7.1)$$

where the w_{ij} are the weights computed from the distances between quadrats i and j as follows:

$$w_{ij} = \begin{cases} 1-(1/r)d_{ij}, \text{ if } d_{ij} \leq r \\ 0 \text{ if, } d_{ij} > r \end{cases}$$

A full account of variogram analysis lies beyond the scope of the current chapter. The salient result in this context is the shape of semivariograms for artifact classes at The Clifts. Although there is variation among semivariograms for different artifact classes, most exhibit sills at a range in the neighborhood of 40 feet. Hence smoothed estimates used below were obtained from Equation 7.1 with r=40.

Maps based on relative frequencies were prepared in a fashion similar to that used for raw artifact counts. Values were interpolated on a regular grid by fitting a surface spline to the known values at quadrat centers. Contour lines were again based on the letter values of the frequency distribution of the mapped variable. In this case, however, deviations both above and below typical values are of equal interest. Hence the chosen letter values were equally distributed on either side of the median at the lower

1/16, 1/8, and 1/4 quantiles, the median, and the upper 1/4, 1/8, and 1/16 quantiles. Solid contour lines represent higher values while dashed lines represent lower ones.

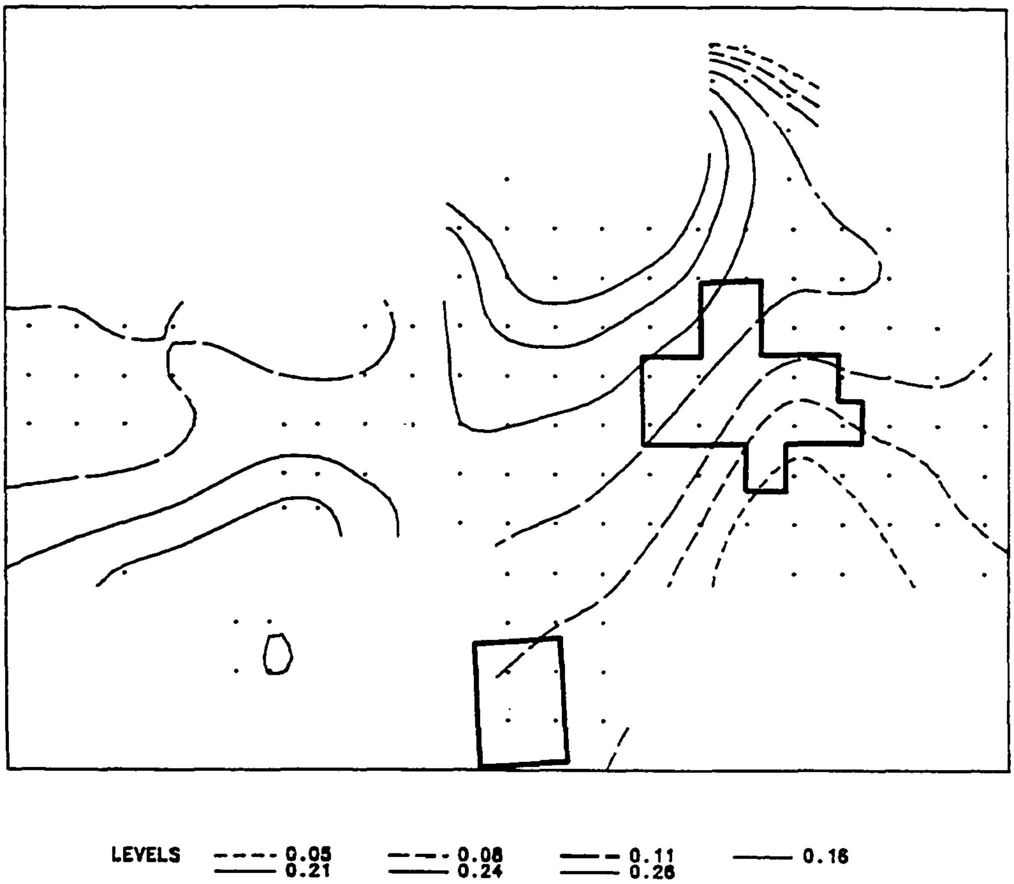


Figure 7.7 Spatial trends in the proportion of red-clay pipes. Contour lines are set at the lower 1/16, 1/8, 1/4 median, upper 1/4, 1/8, and 1/16 of the frequency distribution of proportions.

Spatial patterning in relative frequency was examined for two suites of artifact classes, one intended to define zones associated with laborers and owners respectively, the second intended to define zones in terms of the distinction between general and special-activity areas described earlier. To look at the laborer-owner division, I used red and white pipes. The raw artifact counts were smoothed in the manner outlined above. Relative frequencies were computed from the smoothed quadrat estimates. Since there are only two artifact types, variation can be captured in a single map (Figure 7.7).

Trends in the proportion of red pipes across the site confirm the conclusions that emerged from examination of artifact counts. Most noteworthy is the high proportion of red-clay pipes adjacent to the western room of the dwelling and the attached shed to the north, indicating that laborers were responsible for most of the smoking in this area. Proportions of white-clay pipes are highest on the south side of the dwelling, indicating that most of the smoking is these areas was done by owners. The fact that the quarter falls in this zone comes as a surprise. After all, this building is thought to have been a bulk-processing area that was heavily used by laborers. The anomaly might be accommodated under the hypothesis that while laborers may have used the structure more frequently than owners, it was in the context of work activities which precluded simultaneous tobacco consumption. In other words, laborer smoking tended to be limited to non-work contexts, that is to general-activity areas that, this argument implies, were located on the western end of the dwelling. On the other hand, owner activity in the quarter, although perhaps less frequent, was such that it offered fewer constraints on the frequency of tobacco use.

7.2.3 Patterns of Relative Frequency: Correspondence Analysis

Spatial patterning in the proportions of a second suite of artifact types was examined to measure the extent to which spatial trends in artifact proportions conform to the hypothesized division of the site into general and special-activity areas. The following artifact categories were used: total early pipes (represented by red-clay plus 9, 8, and 7/64th-inch white-clay stems), Staffordshire slipped earthenware, Rhenish stoneware, and Morgan Jones coarse earthenware. The first three of these groups are expected to occur in relatively high frequencies in general-activity areas, and the last is expected to occur in higher frequencies in special-activity areas.

Here we encounter another technical problem: how to portray relative-frequency patterning in more than two artifact types. One solution is to prepare a map for each type. A second solution is to attempt to reduce the dimensionality of the data set so that major spatial trends are captured in fewer dimensions than exist in the original data. The second approach is the one followed here. It has several advantages over the first, not the least of which is the possibility of a simple summary of complex data. However, there is a more important rationale. Attempting to construct a low-dimensional summary of the data offers the opportunity to test the hypothesis that a single factor, in this case the general-special activity area distinction, is the principal determinant of structure in spatial patterning in the proportions of multiple artifact types. If the underlying trends in the data can be captured successfully in a single dimension, then we have additional support for the hypothesis that a single factor does indeed control their relative abundance. In addition, such an analysis offers the opportunity to evaluate the extent to which the contributions of the original artifact proportions to the underlying major dimension of variation conform to the previous arguments about behavioral variation associated with general and special activity areas. For example in the case at hand, we expect that pipestems, fine earthenware, and stoneware lie at one end of any underlying dimension of variation, but coarse earthenwares lie at the other. A final opportunity for evaluation comes when the spatial distribution of the underlying dimension is mapped. As has been the case in our earlier examination of single artifact types, we are interested in the extent to which the resulting spatial pattern conforms to expectations based on architectural documentation of site structure. This last test is available in the examination of artifact proportions one artifact type at a time. However, the first two are not.

The question then becomes how to reduce the dimensionality of the original data. There is a variety of techniques available to accomplish this goal. The one employed here is correspondence analysis. Correspondence analysis (CA) is an ordination technique that allows the rows and columns of a data matrix of counts to be assigned scores in a dual coordinate system of only a few dimensions so that the relationships among both the rows and columns can be displayed. Correspondence analysis has a long and complex history. Originally developed in the 1930's as a way of analyzing two-way contingency tables, French statisticians have since then generalized the technique to handle many-way contingency tables (multiple-correspondence analysis) and a wide variety of other kinds of data (Benzecri 1969, Lebart et al. 1984). The effective promulgation of the technique for the ordination of objects characterized in terms of the presence-absence or frequency of occurrence of multiple characteristics dates to Hill's presentation in an ecological context (1973). Space constraints do not permit a full presentation here. However, since the technique figures importantly in the results that follow and is not well known in archaeology (e.g. Bolvekin, et al. 1982), a brief description is in order.

The correspondence analysis of contingency tables and of data tables of abundances is typically underwritten as a three-step process (e.g. Greenacre and Vrba 1984). First, both the rows and columns of such tables are considered to be points in corresponding spaces. In the case at hand, the quadrats (rows) are points whose coordinates in the space of the artifact types are represented by their smoothed artifact frequencies. The artifact types (the columns) can likewise be considered points in the space of the quadrats. To begin with, consider just the rows. Each quadrat is a point in m-dimensional space, defined by the vector or "row profile" $[p_{i1}/r_i, p_{i2}/r_i, ...p_{im}/r_i]$. The p_{ij} are here the proportions of artifacts of the j'th type found in the i'th quadrat, computed so that the sum of all the p_{ij}, that is the entire data matrix, is 1. There are m types. The r_i are simply the row totals of the matrix p_{ij}. In other words, a row profile is comprised of the counts for a quadrat divided by their sum.

The second step is to define a way of computing distances between the row profiles. The usual approach is to compute Euclidean distances and this is the basis for principle components analysis, an ordination technique more familiar to archaeologists (e.g. Doran and Hodson 1975). However, Euclidean distances are not used in CA. If a particular artifact type is very abundant on the site (it has a high column total), it will dominate the sum of squared differences between corresponding columns of any two row profiles on which the Euclidean distance is based. One way to insure this does not happen, and that the distances are unaffected by overall abundance, is to weight the squared differences between the corresponding elements of two rows inversely by the column totals of those elements. This guarantees that columns with large totals do not unduly contribute to the distance. The result, the chi-squared distance between any two row profiles, say the first and second, is computed as:

$$d_{12} = \Sigma_{j=1}^{m} ((p_{1j}/r_1 - p_{2j}/r_2)^2/c_j) \qquad (7.2)$$

The chi-squared distance has a second advantage over the Euclidean distance. When points are plotted in the space of artifact types, they often form nonlinear shapes. Archaeologists are familiar with this phenomenon in the context of seriation, where it is called the "horseshoe effect" (Kendall 1971). In practice the chi-squared distance captures less of this effect than does the Euclidean distance (e.g. compare Hill 1974 and Kendall 1971), although it does not eliminate it entirely.

Given a set of chi-squared distances among a set of objects, the third step is to find a small number of axes on which to display as accurately as possible those distances among the points. The problem becomes one of finding successive axes through the cloud of row profiles that are in a special sense closest to them. The measure of closeness is a weighted sum of squared distances from the points to the axes (Greenacre and Vrba 1984, Greenacre and Hastie 1987). Making the weights proportional to the totals of the row profiles, insures that the orientation of the axes is influenced more by larger samples where relationships are less affected by the vagaries of sampling. As we shall see, this feature can be used to advantage in a spatial context.

Construction of the new coordinate system is accomplished by computing a dispersion matrix whose elements measure the degree and direction of association between pairs of characteristics. The association measure is based on the sum of cross products of deviations of observed row elements from expected values, under the assumption of row and column independence. The deviations are similar to those whose squared sums comprise the ordinary chi-squared statistic familiar from the elementary analysis of two-way contingency tables. The low-dimensional coordinate system is derived by extracting the eigenvalues and their eigenvectors from this association matrix. As in principal components analysis, the eigenvectors represent the axes of the new coordinate system. The origin of the coordinate system lies at the centroid of the rows, which is simply the row vector of column sums, that is the site-wide relative frequency of types. Finally, the scores of the rows of the data matrix on each axis are computed so that the row points may be plotted in the new space (Legendre and Legendre 1983:296-298). The eigenvalue associated with each axis indicates the adequacy of the representation, which the scores of the rows on that axis offer, of variation among objects in the original space. This measure of goodness of fit is rendered in terms of the percentage of the total inertia in the data, the weighted sum of squared distances from the quadrats to the centroid, accounted for by each axis. The analogy with computation of percentage variance accounted for by an axis from its eigenvalue in a principle component analysis should be evident.

A reduced-space representation of the columns may be had by performing an analogous set of operations, with columns taking the place of the rows and the rows substituting for the columns in the foregoing description. The resulting coordinate system for the artifact types "corresponds" to that for the quadrats in the sense that quadrats lie in the same direction from the origin of the coordinate system as types that are prominent in their composition. Furthermore, when the scores of the quadrats and types on the successive axes are scaled appropriately, the scores of the quadrats are weighted averages of the scores of the types, where the weights are proportional to the importance of types in the composition of the quadrats (Greenacre and Hastie 1987:440, Legendre and Legendre 1983:298-299). This implies that the score of a given type represents the location of a hypothetical quadrat in the coordinate system that contains only that artifact type. This feature is called the "barycentric principle" in the French literature and the formulas describing it are the "transition equations" of CA. The transition equations allow the column scores to be computed directly from the row scores, without a separate analysis.

The fact that the row profile totals provide the weights for the weighted sum of squares that is minimized when the successive axes are fit to the points can be turned to advantage in a spatial context as follows. First, instead of using densities in the analysis, we use raw artifact counts. This means that the few smaller quadrats at The Clifts will be less important in the determination of axis orientation than the large ones. Second, the raw artifact counts are smoothed using a modification of Equation 7.1 that yields the raw weighted sums of artifact counts, undivided by the sums of the weights. In other words, the numerator of Equation 7.1 provides the input for CA. This effectively reweights each smoothed estimate by the number and inverse distance of the quadrats that went into the estimate. As a result, quadrats that are isolated or located on the edges of the excavation will have less influence on the axis orientation than those in the middle. This is desirable since the row profiles computed from values of smoothed estimates for smaller, edge, or outlying quadrats will have greater random error variance associated with them. All computations were performed following the algorithm provided by Legendre and Legendre (1983), programmed by the author (SAS Institute 1985b).

Table 7.1 Scores of four ceramic types from Phases 1 and 2 on CA axis 1.

Score	Type
-0.95	Staffordshire Yellow Slip Earthenware
-0.49	Rhenish Brown Stoneware
-0.41	Red-Clay and 9,8, and 7/64-inch White-Clay Pipes
2.04	Morgan Jones Coarse Earthenware

Correspondence analysis of the matrix of weighted estimates for the four artifact types from Phases 1 and 2 indicates that the spatial trends in relative frequency at the site are well summarized in a single dimension. The first axis of the analysis accounts for 87 percent of the inertia in the data. Just as important for current purposes is the fact that the positions of the artifact types on this axis match the expectations developed in our earlier arguments concerning special and general activity areas (Table 7.1). Morgan Jones is located on one end of the axis. Total pipes, Staffordshire Yellow Slip, and Rhenish Brown are clustered together on the opposite end. This implies that the single factor that controls variation in relative frequencies for these four artifact types at the site is the special-general activity area distinction.

Plotting the scores of the quadrats on this axis makes it possible to see just where along the activity-area gradient quadrats fall. From the earlier discussion of the barycentric principle, it should be clear that quadrat profiles with the lowest scores will be dominated by slipped earthenware, those with moderately low scores will be dominated by pipes and Rhenish brown, and those with the high scores will be dominated by Morgan Jones. Figure 7.8 shows that axis 1 scores are high to the north, west, and south of the dwelling but lower in the area centered on it. The east side of the dwelling has lower scores than the west side. To some extent this is a result of the large

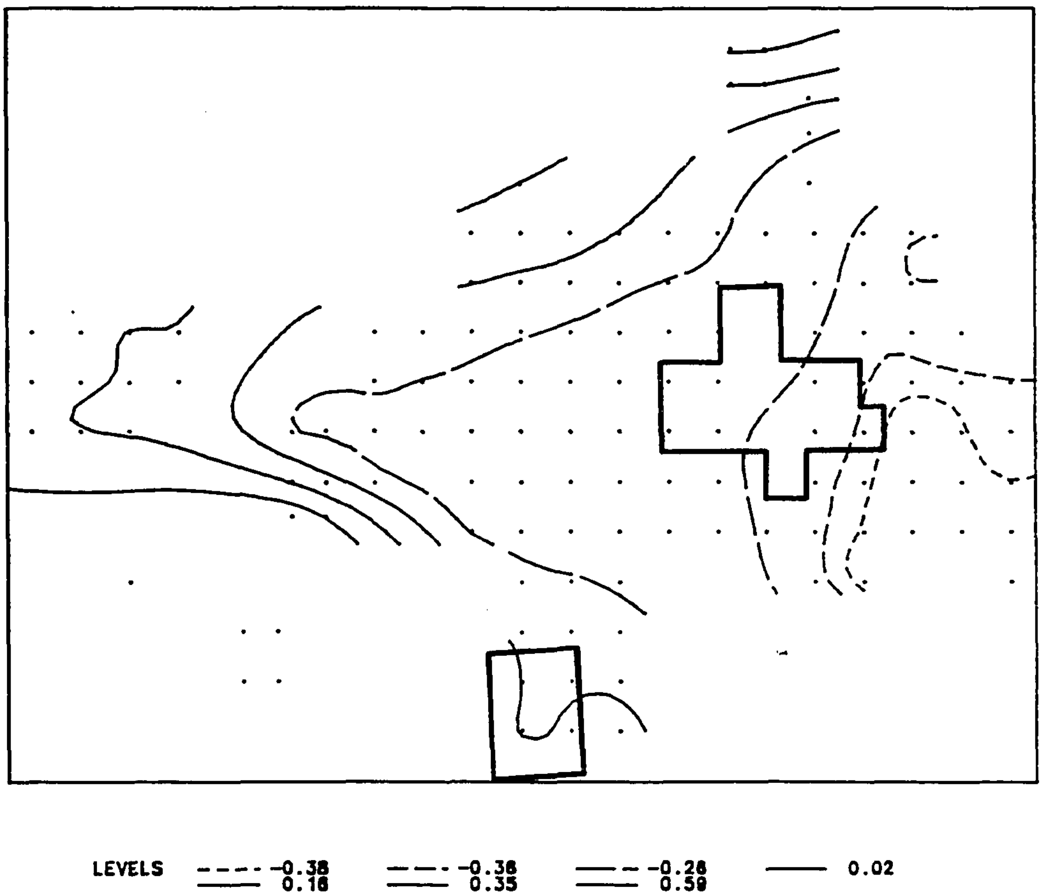


Figure 7.8 Scores of quadrats on the first axis from CA of 4 artifact types from Phases 1 and 2.

quantity of Staffordshire Yellow Slip recently plowed from the Phase-2 pit cluster southeast of the dwelling. However, it also reflects the mixed use of the western end of the dwelling both as a living and work area, and the absence of bulk-processing from the east end. Quadrats over the early quarter have high scores. Those adjacent to the Phase 1 and 2 smokehouses have even higher ones. So do areas lacking outbuildings. This suggests that the early quarter was more of a special-activity area than either the dwelling as a whole or its western end considered alone. In addition it is evident that some special activities took place outdoors on the periphery of the excavated area. CA reveals that the site can be divided into two zones: a general-activity area centered on the dwelling and a special-activity area surrounding it on the north, west and south that includes the early quarter.

The results from the foregoing analysis of plowzone artifact distributions fit nicely with earlier inferences about the use of space during the first half of the occupation based on architectural evidence. The dwelling emerges as the primary general-activity area at the site, although its western was also used for bulk processing. The early quarter seems by contrast to have been largely a bulk processing facility. Both social groups at the site, laborers and owners, spent most of their (non-work?) time in or adjacent to the dwelling, although there is evidence that their use of the partitioned spaces of this single structure was differentiated.

7.3 Phase 3 and 4 Ceramic Distributions in Plowzone

In this section I offer a complementary examination of patterning of ceramics dating to the second half of the occupation. The exposition is similar to that for Phases 1 and 2. First I consider spatial variation in the density of the same single artifact classes examined above: coarse earthenwares, pipes, fine earthenwares and stoneware. Next I turn to an analysis of relative frequencies of this suite of artifact classes, designed to elucidate the general-special activity area distinction. Finally, I consider variation in relative frequencies within the fine earthenware and stoneware group to shed light on the question of the spatial segregation of the living space of laborers and owners.

7.3.1 Patterns in Absolute Frequency

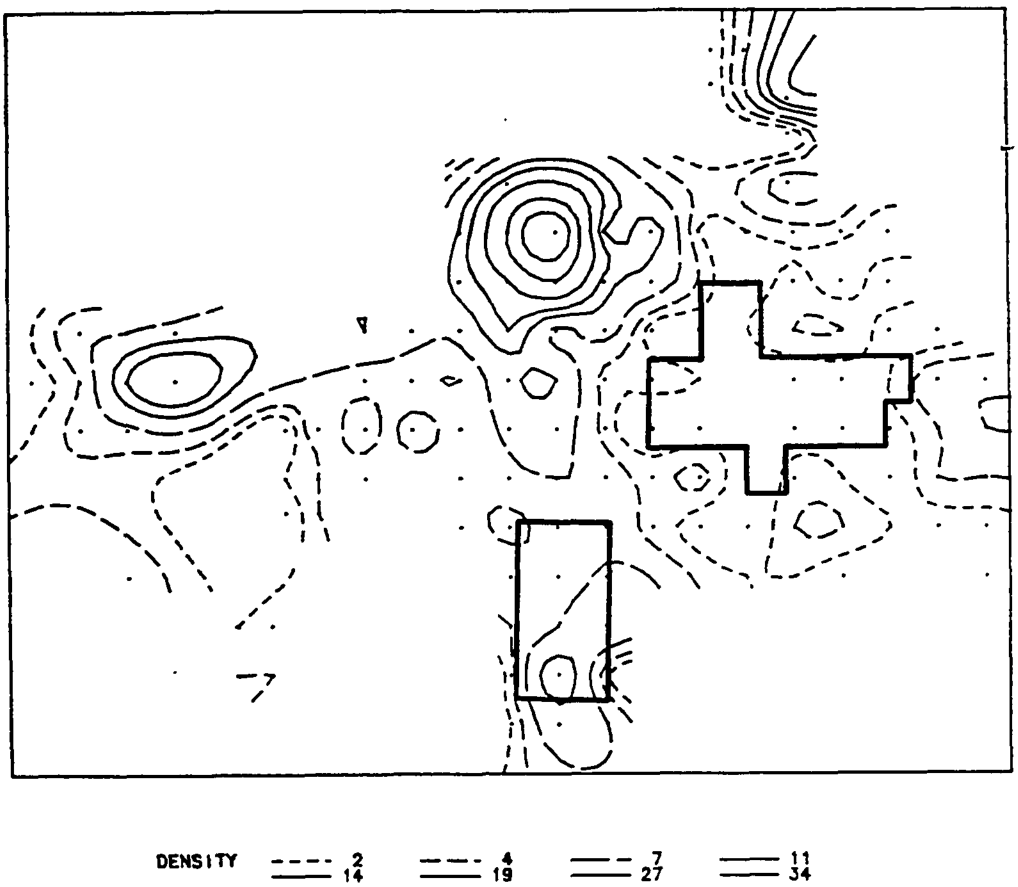


Figure 7.9 Plowzone distribution of Black-Glazed and Buckley Earthenware.

The number of artifact classes, most of whose members were deposited during the first half of the occupation, was fairly small. By contrast, more ceramic ware types can be dated to Phases 3 and 4. This is the result of two factors. Many classes were only introduced to the site during the second half of the occupation. For others in use on the site throughout the occupation, site-wide counts of the minimum number of vessels in a given ware initially stratified during each phase reveal that most vessels, and therefore plowzone sherds, were deposited during the second half of the occupation.

Black-Glazed Earthenware and Buckley Earthenware fall in the former category. These coarse earthenwares occur in several shapes on the site: milk pans (4), pots (5), and bottle (1). Our earlier arguments suggest that the ware should be associated with bulk-processing activities. Its distribution at the site is shown in Figure 7.9. There are five areas on the site where the frequency exceeds the upper 1/8 quantile definition of a midden. Four of these are arrayed along the north edge of the site, along with the smaller Phase-3 and 4 outbuildings. The largest of these is located adjacent to Structure 11, the 8-by-10 foot outbuilding northwest of the dwelling whose construction dates to Phase 3. Middens also occur adjacent to Structure 12, a Phase-4 outbuilding to the north of the dwelling and Structure 10, a second Phase-4 outbuilding just west of Structure 11. The fourth concentration is located next to superimposed Structures 8 and 9 on the western edge of the site. Finally, there is a small concentration beneath the later quarter (Structure 3). However, the conclusion that emerges is that bulk-processing activities related to this ware were nearly exclusively being carried out in the outbuilding that appeared on the northern edge of the site during the occupation.

Earlier I used large 9, 8, and 7/64th-inch clay pipestems as indicators of overall use frequencies of different areas for the first half of the occupation. Pipestems with bore diameters of 6 and 5/64th inch can be put to similar use for Phases 3 and 4. There are two concentrations of 6/64th-inch pipes on the site. One is located over the Phase-3 pit cluster roughly 60 feet west of the dwelling. The other, much larger, runs the length

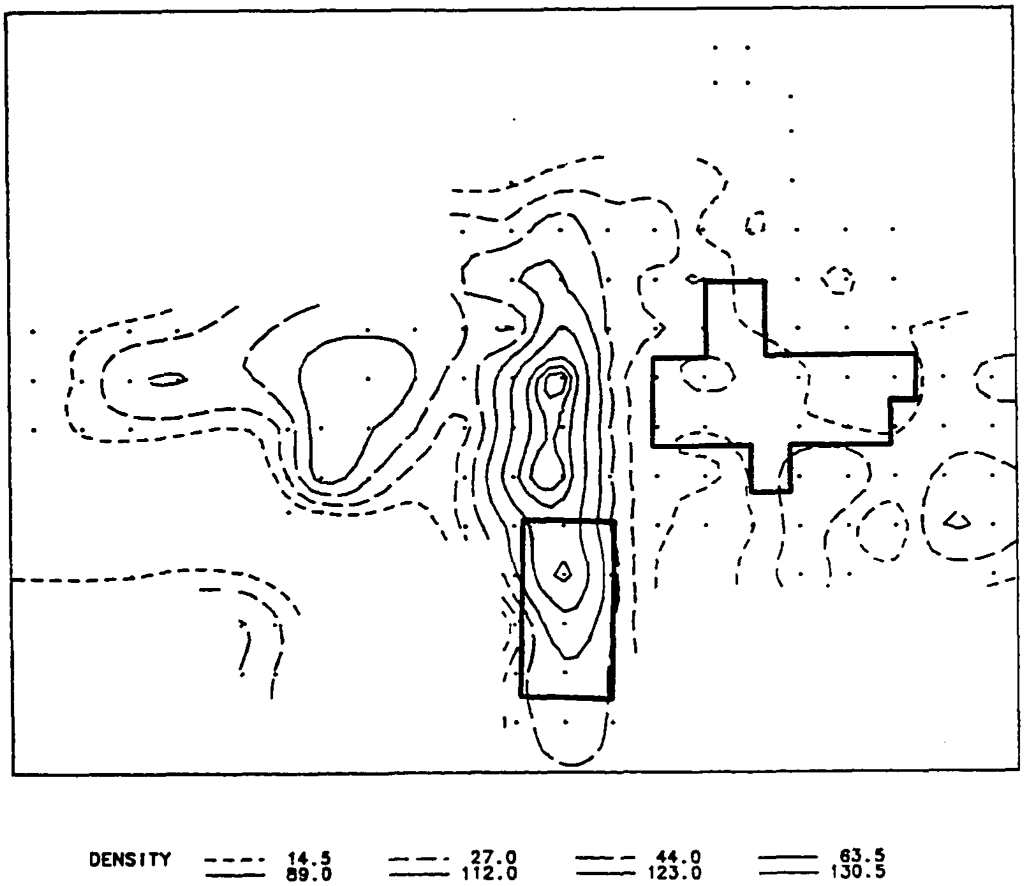


Figure 7.10 Plowzone distribution of 6/64th-inch pipestems.

of the quarter and extends north of it, adjacent to the west gable of the dwelling. If the pipes in that portion of the midden closest to the quarter were for the most part derived from it, and those closest to the dwelling were derived from it, then frequency of smoking was about the same in the two structures. This represents a contrast with the first half of the occupation when few pipes were associated with the early quarter. That the new situation lasted until the end of the occupation is indicated by the fact that the distribution of 5/64th-inch pipes is nearly identical to the 6/64th-inch pattern. This offers an initial indication that during the second half of the occupation both the quarter and dwelling served equally important roles as general activity-areas.

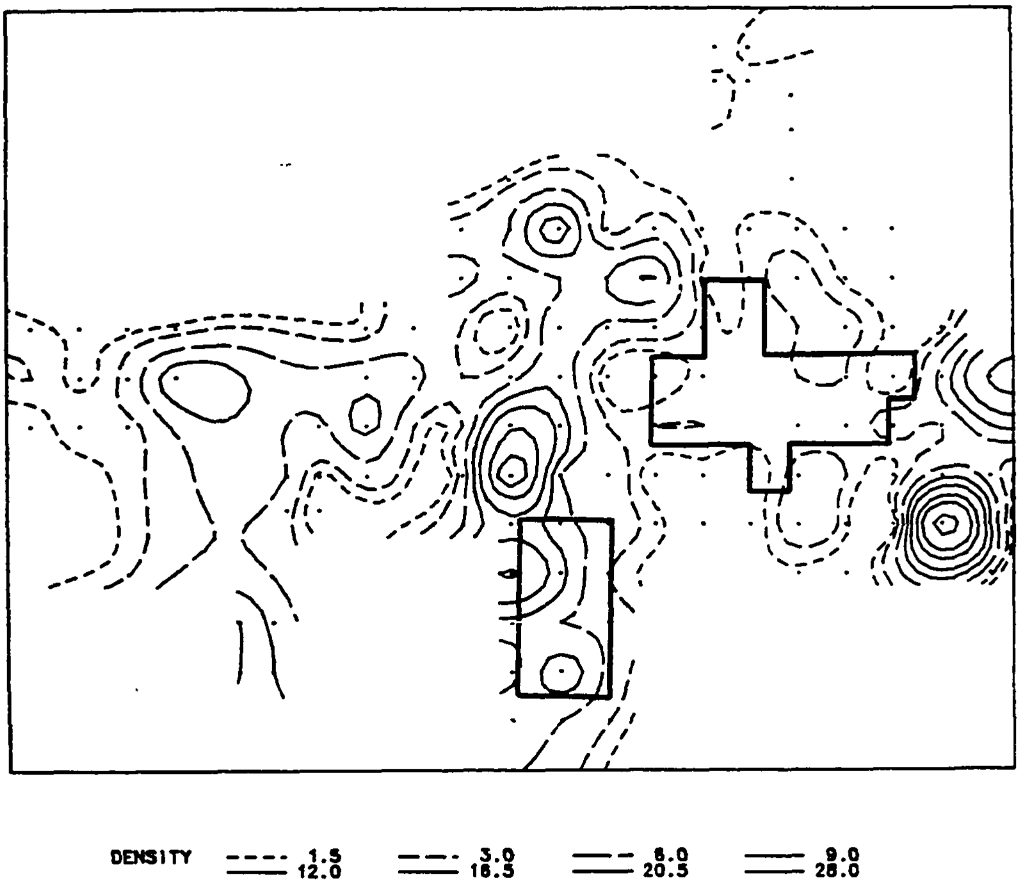


Figure 7.11 Plowzone distribution of North Devon Gravel-Tempered Earthenware.

Additional support for this hypothesis comes from the distribution of North Devon Gravel-Tempered Earthenware on the site. Recall that both its paste characteristics and shapes suggest that this ware was used in cooking. Recall too that this ware was in use throughout the occupation, with most of the vessels identified dating to

Phases 3 and 4. Although the plowzone distribution of the ware is a palimpsest of 60 years of deposition, much of the patterning should date to Phases 3 and 4 (Figure 7.11). The pattern is noisy, with multiple concentrations. Its most striking aspect is the contrast with the distribution of Black-Glazed and Buckley Earthenware, a difference that indicates that the two coarse earthenwares were in fact used very differently. One of the North Devon concentrations, located just southeast of the dwelling over the Phase-2 pit cluster, clearly is the result of plowing. Several concentrations are located beneath the quarter. A concentration just north of it may contain deposition from both the quarter and the dwelling. Two concentrations just northwest of the dwelling presumably contain sherds derived from it, although they may date to the first half of the occupation when this area also was the site of deposition of Morgan Jones. Finally, a concentration off the east gable end of the dwelling is certainly derived from it. Although the inability to control time introduces uncertainties, both the quarter and dwelling appear to have been sources of North Devon sherds and hence sites of cooking.

As we have seen, frequencies of fine earthenwares and stoneware should correlate with frequencies of food and drink consumption and thus offer additional clues to general-activity area locations. Whereas for the first half of the occupation, only single stoneware and fine earthenware types were available for analysis, for the second half of the occupation there are several types in both categories. Some of the ware types were introduced to the site for the first time during Phases 3 and 4 (see Table 6.2). The stoneware types unique to this period are: Rhenish Blue-Grey, Burslem-Nottingham, Staffordshire Brown, and English White. Although Rhenish Brown Stoneware was present at the site from Phase 1, those sherds that belong to vessels initially stratified

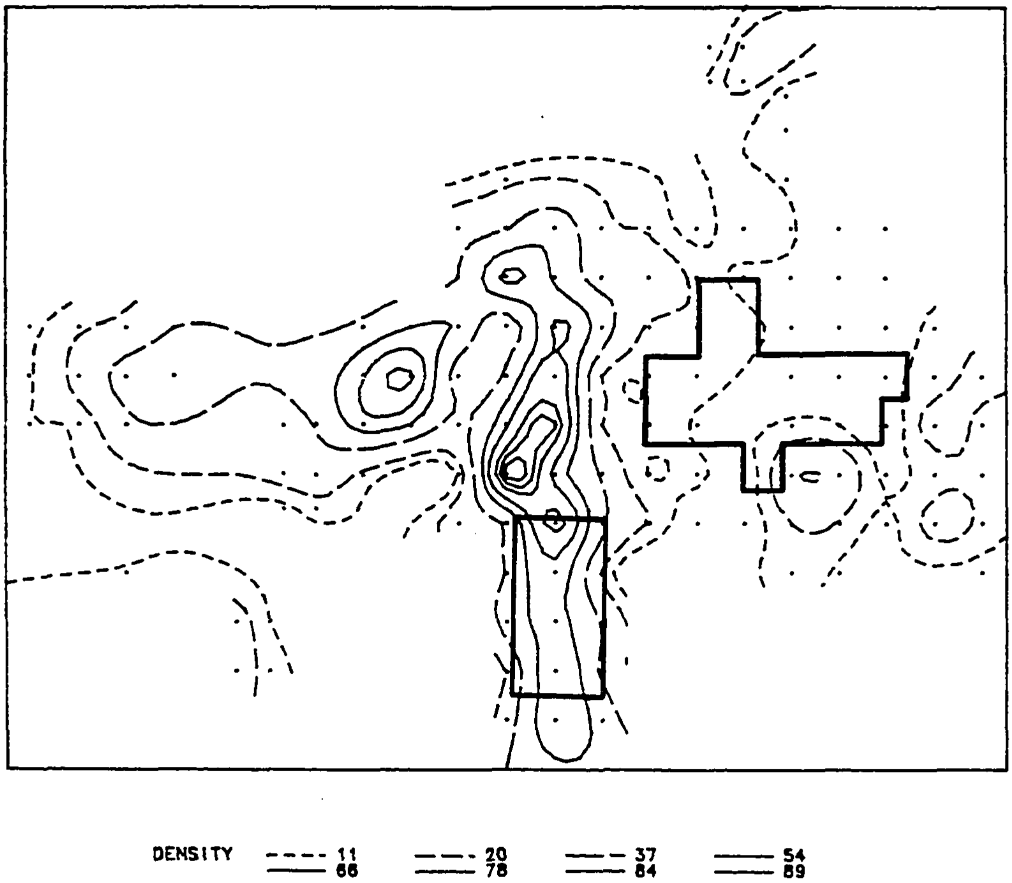


Figure 7.12 Plowzone distribution of fine earthenwares whose deposition can be dated to Phases 3 and 4.

during the second half of the occupation are readily identifiable. Two fine earthenwares were Phase 4 introductions: Staffordshire Brown Slip and Staffordshire Manganese Mottled. Accurate counts of Staffordshire Yellow Slip sherds dating to the second half of the occupation could be had by excluding those sherds assigned to Phase 2 on the basis of decorative technique. Tin-Glazed Earthenware sherds were also included in the total fine earthenware map. Despite the fact that the ware was present on the site from Phase 1, the great majority of vessels in the site-wide minimum vessel count date to Phases 3 and 4 (101 out of 110). The frequencies of these ware types were summed to obtain total counts of fine earthenware and stoneware for Phases 3 and 4.

Two major concentrations are evident on the fine earthenware map (Figure 7.12). The smaller lies over the Phase-3 pit cluster 50 feet west of the dwelling. The larger stretches the length of the quarter northward past the west gable of the dwelling. Its shape and the location of concentrations within it indicate contributions from both structures.

The stoneware map leads to similar conclusions (Figure 7.13). There are three concentrations defined by the 1/8 letter value level. The smallest lies over the Phase-3 pit cluster. The largest stretches from beneath the north room of the quarter to Structure 11. Within it three peaks can be identified, beneath the quarter, due west of the dwelling gable, and next to Structure 11, each of them caused by deposition from the respective adjacent buildings. The third midden is situated beneath the south end of the quarter. Like fine earthenwares, stoneware saw frequent use in both dwelling and quarter. Unlike fine earthenwares, they also were frequently used in Structure 11, an hypothesized bulk processing site. This makes sense since higher firing temperatures associated with stoneware bodies cause increased resistance to crack initiation. Hence, given equally fine pastes, stonewares are better suited to high matter-energy flows than fine earthenwares.

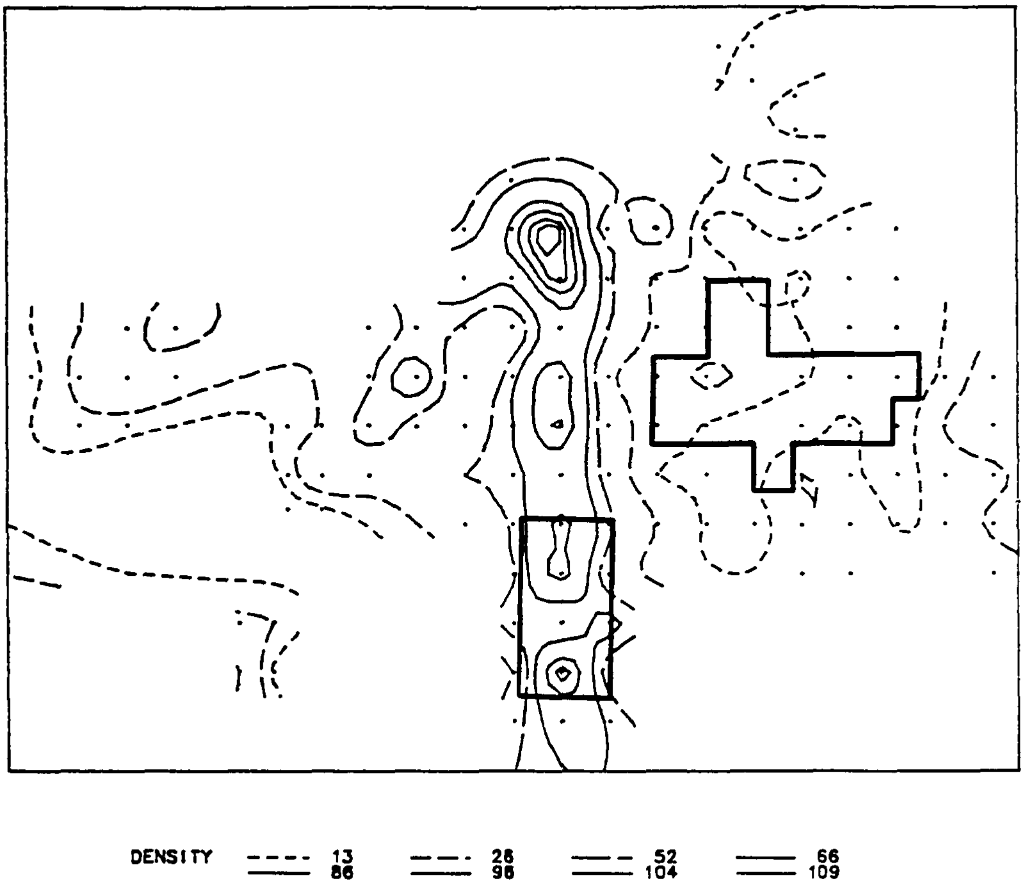


Figure 7.13 Plowzone distribution of stoneware sherds whose deposition can be dated to Phases 3 and 4.

7.3.2 Patterns in Relative Frequency

The picture developed so far of activity structure during the second half of the occupation can be tested with the help of a correspondence analysis of patterning in relative frequency of ceramics whose deposition dates to that period. The five ceramic types whose individual density patterns were described above were used in this analysis. Four of them are analogues to the four types used in the CA of early artifact distribution: total white-clay pipes (5 and 6/64th-inch stems combined), total fine

Table 7.2 Scores of 5 ceramic types from Phases 3 and 4 on the first axis of correspondence analysis of smoothed plowzone counts.

Score	Type
4.20	Black-Glazed and Buckley Earthenware
1.14	Total Stoneware
0.32	Total Fine Earthenware
0.09	North Devon Gravel-Tempered Earthenware
-0.62	White-Clay 6 and 5/64th-inch Pipes

earthenwares, total stoneware, and Black-Glazed and Buckley Earthenware, the coarse earthenware likely to have been used in bulk-processing activities. The fifth ceramic type included was North Devon the presumed cooking ware. The expectations for the outcome of the analysis, based on the hypothesis that the general-special activity area distinction controls their distribution across the site are explicit. A single axis should underlie site-wide variation. One end of that axis should be dominated by North Devon, fine earthenwares, stoneware, and pipes, and the other should be dominated by Black-Glazed and Buckley Earthenware.

Raw artifact quadrat counts were smoothed and row profiles weighted as described earlier. The results of the analysis meet our expectations (Table 7.2). The first CA axis accounts for 80% of the inertia in these data. Although the four members of the general-activity group straddle the centroid, they clearly cluster together near the high end of the first axis, but Black-Glazed and Buckley Earthenware falls far from them at the opposite end. The fact that high densities of stoneware are associated with an outbuilding is faithfully reflected here in the fact that among the ceramic types clustered at the high end of the axis, stoneware has the lowest score. The spatial patterning of quadrat scores on this axis shows the expected pattern (Figure 7.12). Quadrats with low scores are arrayed along the northern edge of the site, along with the Phase 3 and 4 outbuildings. The quarter and dwelling fall squarely in areas with high scores. The highest scores on the site occur over an early Phase 3 pit cluster, an artifact of the

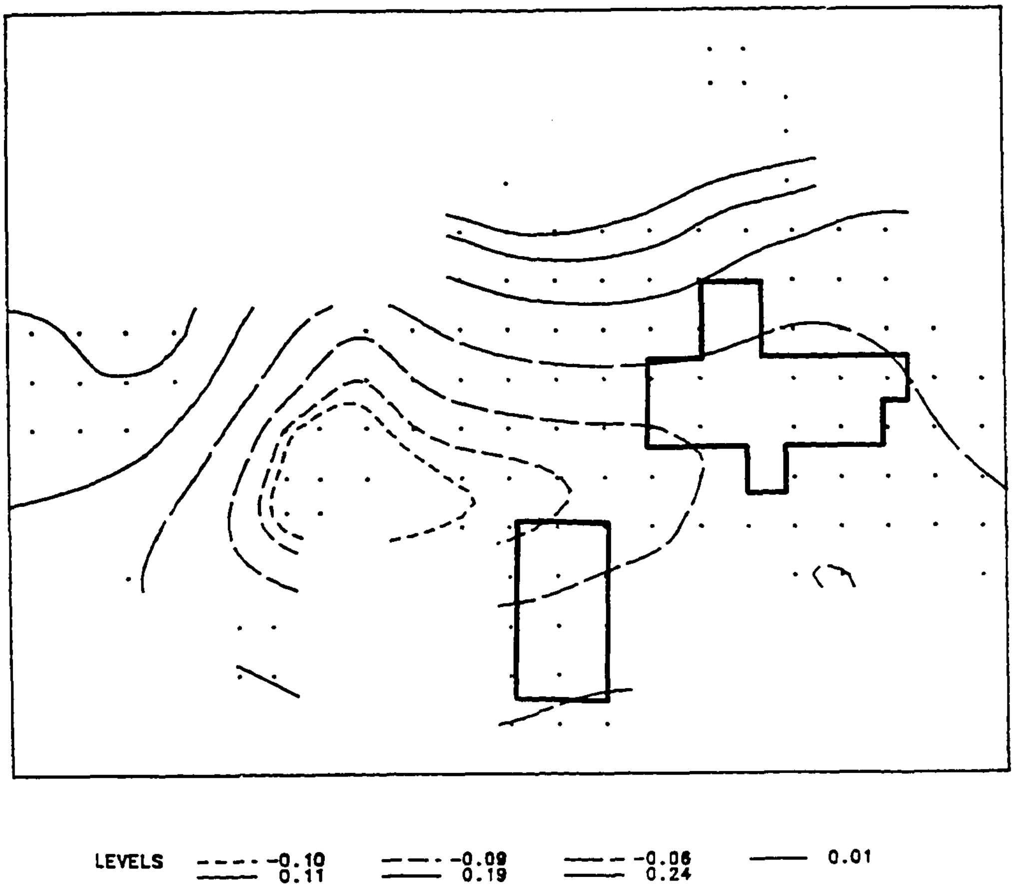


Figure 7.14 Quadrat scores on CA axis 1 for five artifact types from Phases 3 and 4.

relative scarcity of Black-Glazed and Buckley Earthenware on the site at the time of its filling. However, only a small portion of the site-wide patterning is caused by this temporal component. The analysis once again confirms that quadrats can be assigned a position along a general-special activity area gradient. However, in contrast to the pattern for Phases 1 and 2, both the quarter and dwelling fall on the general-activity end of the continuum, while the outbuildings at the edge of the site fall on the special-activity end of it. The conclusion is that both the quarter and dwelling served as general-activity areas during Phases 3 and 4. Special-activity areas were now housed in outbuildings.

It still remains to determine whether the dwelling and quarter were used by owners and laborers. Since red-clay pipes went out of use at the end of Phase 1, we must rely on patterning in other artifact classes. As suggested earlier, an initially promising place to look for such patterning is among fine earthenwares and stoneware in use on the site during the second half of the occupation. Nearly all of these types occur in shapes associated with food consumption. Stoneware sherds at the site are derived exclusively exclusively from liquid containers. Two stoneware types, Rhenish Blue-Grey and Burslem-Nottingham, occur in both mugs and jugs and it is possible to make unambiguous shape distinctions for nearly all sherds. The other stoneware types occur exclusively, or nearly so, in a single shape. Thus all the Staffordshire Brown Stoneware sherds on the site are derived from mugs, as are nearly all sherds of White Stoneware. Rhenish Brown Stoneware sherds are limited to large bottles. Two earthenware types are similarly limited to drinking vessels, Staffordshire Brown Slip Earthenware occurs in mugs (6) and cups (1). Staffordshire Manganese-Mottled Earthenware occurs only in cups. Two earthenware types, Staffordshire Yellow Slip and Tin-Glazed Earthenware occur in a wider variety of shapes, including both flat and hollow forms. In addition to these 11 ceramic types, two types of glass are also included in the analysis, Wine Bottle Glass and Clear Table Glass. The latter category includes both stemmed and non-stemmed hollow vessels.

It is expected that site-wide variation in relative use frequency of these types of ceramics will be correlated with social-group membership. There is considerable redundancy within the fine earthenware and stoneware groups in performance characteristics caused by shared paste and vessel shape characteristics. Toughness of German stoneware bodies is unlikely to differ significantly from toughness of English ones. Rhenish stoneware mugs should perform similarly to English white stoneware mugs. Hence variation will not be a function of spatial differentiation along the activity structure gradient discussed above. Rather it is likely to have been controlled by other causes. The first of these is drift-driven divergence between the two groups in preferences for certain kinds of ceramics over others. This implies little or no cultural transmission between groups. The second is functional divergence between the two groups related, on the one hand, to differences between laborer and owners in resource access and, on the other, to differences in acquisition costs for the different wares. A third possibility combines these two causes of between-group divergence. Separating these possibilities will be difficult and is not

Table 7.3 Scores of 13 artifact types from Phases 3 and 4 on the first axis of correspondence analysis of smoothed plowzone counts. Derivation of temporal ranks of 12 types included in the occurrence seriation is described in the text.

Score	Type	Code	Temporal Rank
1.58	Rhenish Blue-Grey Mugs	RHBG_M	3
0.74	Wine Bottle Glass	WBG	-
0.65	Staffordshire Manganese Mottled Earthenware	SMEW	6
0.27	Rhenish Blue-Grey Jugs	RHBG_J	3
0.13	Rhenish Brown Stoneware	RHBRSW	5
-0.21	White Stoneware Mugs	WS_M	5
-0.29	Staffordshire Brown Slip Earthenware	SBEW	6
-0.56	Table Glass	TG	1
-1.28	Staffordshire Brown Stoneware	SBSW	4
-1.33	Tin-Glazed Earthenware	TGEW	1
-1.38	Staffordshire Yellow Slip Earthenware	SYSEW	1
-2.66	Burslem-Nottingham Stoneware Jugs	BNSW_J	2
-3.05	Burslem-Nottingham Stoneware Mugs	BNSW_M	2

attempted here. All that is required for current purposes is that use frequency for different ceramics correlate with group membership.

The results of the correspondence analysis, performed on smoothed raw artifact counts and weighted row profiles, are considerably more complex than we have encountered in earlier applications. Previously variation could be captured with a single axis. In the case at hand, three axes, are required for an adequate summary of spatial variation. The first three axes to emerge from the analysis account respectively for 41, 31, and 11 percent of the inertia in the data.

The first axis is dominated at the low end by Burslem and Nottingham mugs and jugs, with smaller contributions from Staffordshire Brown Stoneware and Yellow Slip Earthenware (Table 7.3). At the opposite end lie Rhenish Blue-Grey mugs and Wine Bottle Glass, although these are less important in determining the orientation of the axis than the Burslem-Nottingham mug and jug sherds. Mapping the scores of the quadrats on the first axis helps isolate just what it measures (Figure 7.15). Quadrats with low scores overlie the Phase-3 pit cluster west of the dwelling. Within the area of low scores, the lowest occur over the earliest Phase-3 pits within the cluster. High scores on the other hand occur over the Phase-4 pit cluster at the north edge of the site. The relationship between quadrat scores and pit locations indicates that the first axis of the analysis is a function of change over time at the site.

A consideration of type scores makes possible a second assessment of relationship between the first axis and time. If the first axis is temporally sensitive, then the positions of types along it should be related to the sequence in which they appear in stratified deposits. The latter information is supplied by the occurrence seriation of the previous chapter (Table 6.2). Types in the seriation were assigned temporal ranks on the basis of their order in the occurrence seriation. All types whose initial introduction to the site preceded the beginning of Phase 3 received a rank of 1. A fair test requires adjustment of temporal ranks for types that went out of use after their initial

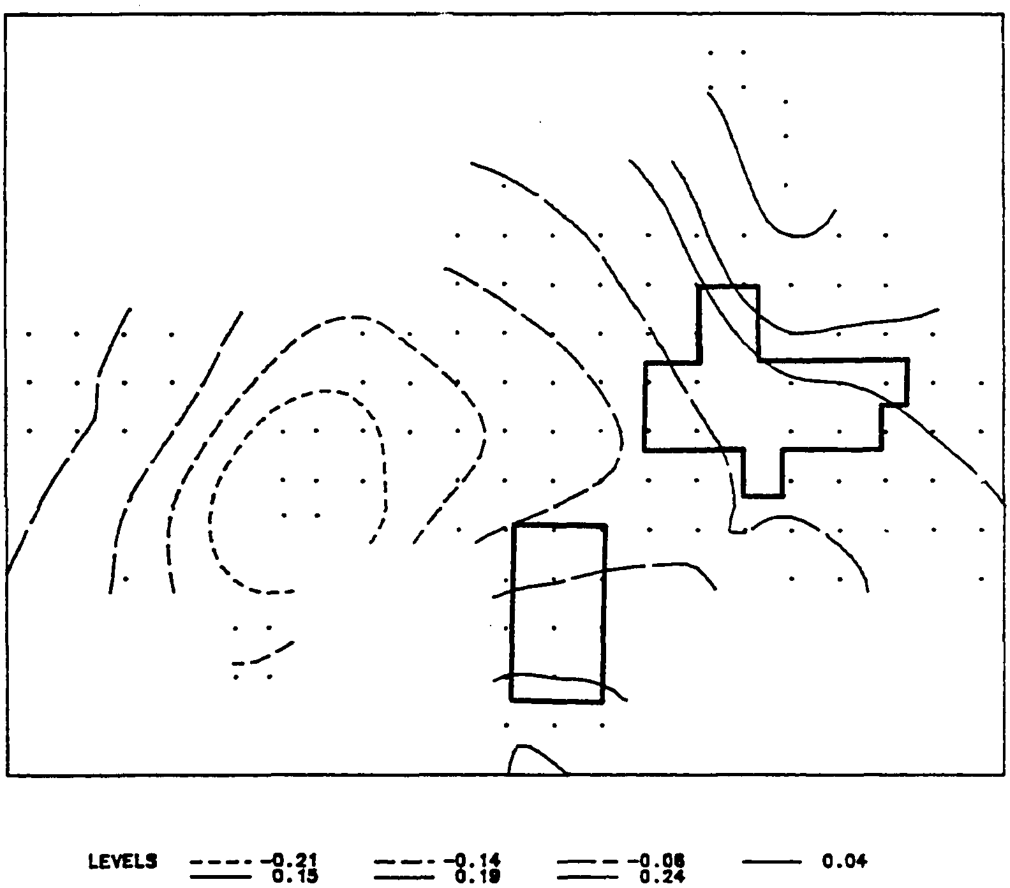


Figure 7.15 Spatial distribution of quadrat scores on the first axis of correspondence analysis of smoothed plowzone counts for 13 Phase-3 and 4 artifact types.

introduction to the site and then reappeared later. Counts of the number of vessels whose sherds were initially stratified in each phase indicate that there was only one: Rhenish Brown Stoneware for which no vessels were deposited in Phase 3. It was assigned a rank of 5, on the assumption that its reappearance coincided with the beginning of Phase 4. Measuring the correlation between the ranks of the first axis scores and the temporal ranks of the types (Table 7.3) reveals a relationship in the expected direction that is unlikely to be the result of chance (Spearman's $r=.60$, $p=.048$; Kendall's $\tau=.37$, $p=.09$). Note too that Burslem-Nottingham stoneware, whose abundance or lack thereof is the most important contributor of axis 1, is the first ceramic type to be introduced to the site at the beginning of Phase 3 (Table 6.2).

The foregoing indicates that areas that score low on the first axis are those in which deposition was heavy in Phase 3, relative to deposition in Phase 4. Conversely, high scoring areas received greater deposition in Phase 3, relative to what they would receive later. Apparently use frequencies for both the east end of the dwelling and the quarter increased from Phase 3 to Phase 4. In a similar fashion, types that score low on the first axis are those that were deposited in areas that received higher deposition in Phase 3 than in Phase 4. High scoring types are those that were deposited in areas in which depositional rates were relatively low until the last phase of the occupation.

For reasons that will soon be apparent, it is helpful to consider the scores of artifacts and quadrats on the second and third CA axes taken together. Consider first the positions of the quadrats in multidimensional space, based on their scores on the second and third axes (Figure 7.16). The point cloud resembles a three-pronged star.

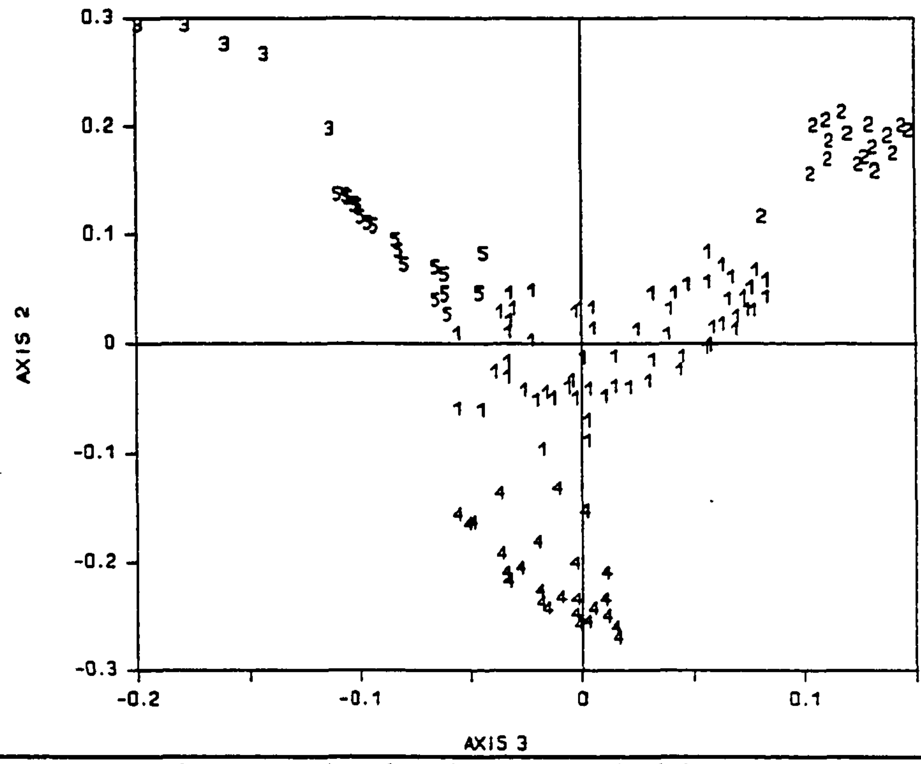


Figure 7.16 Quadrat scores plotted on the second and third axes from CA of smoothed plowzone counts for 13 Phase-3 and 4 artifact types.

Quadrats are arrayed along one of three gradients extending from the center of the star to each of the three points.

Just what each of these gradients represents in terms of relative artifact frequency becomes apparent from a consideration of the scores of the artifact types on the second and third axes (Figure 7.17). Note how they have a similar three-pronged configuration. Recall from the earlier discussion of correspondence analysis the relationship between the space of the quadrat scores and the space of the artifact scores. Quadrats lie in the same direction from the origin of the coordinate system as artifact

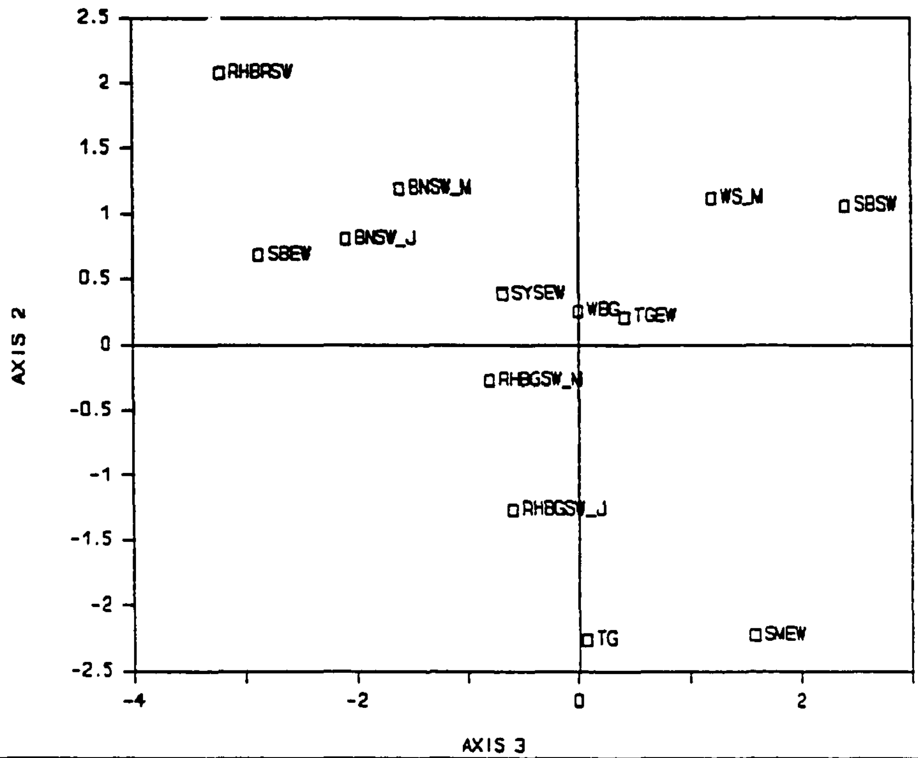


Figure 7.17 Scores of 13 artifact types from Phases 3 and 4 plotted on the second and third axes from correspondence analysis of smoothed plowzone counts.

types whose relative frequencies are high in those quadrats. Hence each of the three gradients is characterized by higher frequencies of a distinctive set of artifact types as one proceeds from the origin of the coordinate system out to the ends of the three prongs. The first gradient (upper left quadrant of Figure 7.17) is distinguished by higher frequencies of both Burslem-Nottingham mugs and jugs, Rhenish Brown Stoneware, and Staffordshire Brown Slip Earthenware. The second gradient (upper right quadrant) is characterized by higher frequencies of White Stoneware and Staffordshire Brown Stoneware. The third gradient (bottom two quadrants) represents increasing proportions of Rhenish Blue-Gray jugs, Table Glass, and Staffordshire Manganese-Mottled

Earthenware. The four artifact types that are located near the center of the star are those that show much less distinctive variation around the site, once time-correlated depositional differences have been removed by the first axis. These are Rhenish Blue-Gray mugs, Tin-Glazed Earthenware, Wine Bottle Glass, and Staffordshire Yellow Slip Earthenware.

The analysis has lead to the identification of three gradients in artifact space. Where do these gradients fall in geographical space? Given the nature of the relationships between the axis scores and the gradients, the answer cannot be had by simply plotting the axis scores as I have done earlier. Note for example that quadrats along both the first and second gradients will score high on axis 2. An intermediate step is required in which quadrats are first assigned to groups on the basis of their scores and then locations of the groups are plotted on the site. This intermediate step was accomplished by clustering the quadrats on the basis of their scores on the second and third axes using a k-means algorithm (SAS Institute 1985c:377-402). Cluster assignments from the five-cluster solution are shown in Figure 7.16. Clusters 5 and 3 fall on the first gradient. Clusters 1 and 2 fall on the second gradient. The third gradient is occupied by cluster 4.

Plotting the cluster locations on the site (Figure 7.18) reveals that the three gradients are spatially contiguous. The cluster locations make it plain that the position of a quadrat along the gradient is correlated with the distance from the center of the site. This is an important point. It means that the clusters are not to be understood as 5 different "activity areas" (cf. Whallon 1984, Carr 1984). Rather the cluster solution is

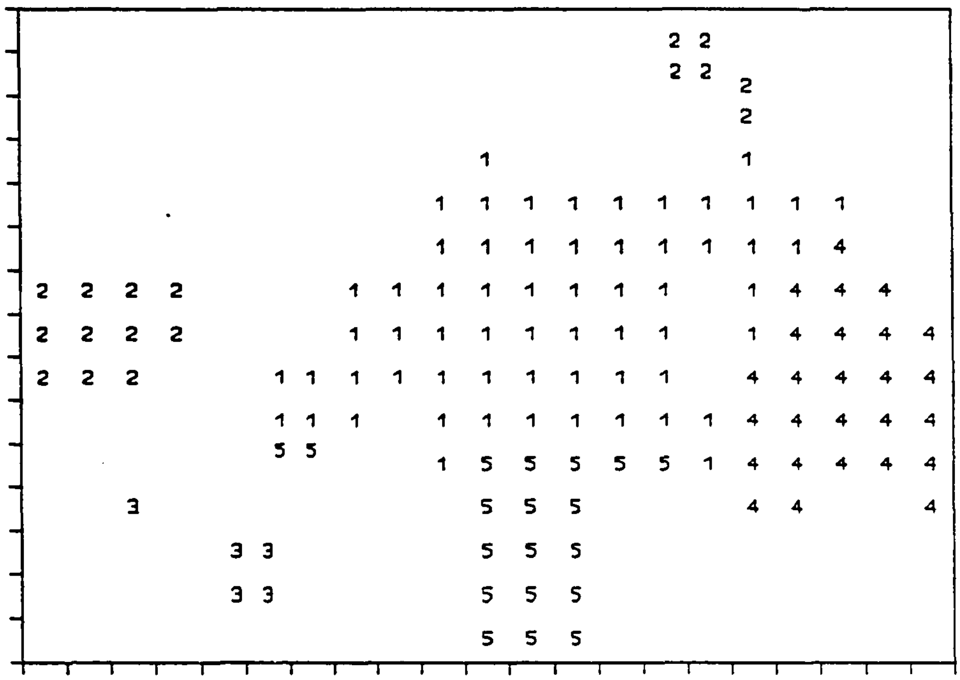


Figure 7.18 Cluster membership of quadrats from k-means clustering of quadrat scores on the second and third axes from correspondence analysis of smoothed plowzone counts.

simply a convenient tool by which quadrat positions along each gradient can be related to positions in geographical space. The phenomena of interest are three gradients. The three gradients divide the site into three wedges. Note the contrast between this wedge pattern and center-periphery zonation identified in the two previous correspondence analyses of different suites of artifact types. As was expected on the basis of the artifacts that went into the current analysis, the wedge pattern is unrelated to the general-special activity area gradient. This independence offers some support for the hypothesis that the wedge pattern is related to variation in cultural repertoires among social groups at the site, caused by different histories of stochastic sorting within each group and/or deterministic sorting based on differences in resource access.

The first of the three gradients (clusters 3 and 5) is associated with the quarter and the adjacent southern portion of the site. Thus the analysis reveals the expected differentiation between social groups in use frequencies for the quarter and dwelling. What is unexpected is the existence of not just one additional gradient corresponding to the dwelling but two. The second gradient (clusters 1 and 2) is associated with the hall or western side of the dwelling. The third gradient (cluster 4) is associated with the parlor or eastern side of the dwelling. Note how the spatial division between quadrats at the origin of each gradient corresponds exactly to the location of the archaeologically documented partition between the two rooms. The implications are unclear. Two possibilities can be mentioned. The division represents the spatially differentiated expression of a single stylistic repertoire. That is, stylistic behavioral prescriptions shared by members of a single group map different behaviors onto different architectural contexts. The division might also represent two stylistically different cultural repertoires and hence two different subgroups within the owner group. Males and females are an obvious possibility. Whatever the cause, its investigation falls outside the purview of the current argument. Note there is no analogous division between the two rooms of the quarter.

In the previous two sections I have characterized changes in the use of space on the site on the basis of functional-morphological arguments coupled with evidence from the distribution of artifacts in plowzone across the site. The motivation for this was an assessment of the congruence between inferences derived from this source and from similar arguments developed in Chapter 6 from architectural evidence. Both data sources point to change at the Phase 2-Phase 3 boundary at The Clifts in three dimensions of behavioral variation. These changes were the removal of bulk-processing activities from the dwelling to outbuildings, the emergence of two general-activity areas on the site, where previously there had been one, and the exclusive use of these two areas by two different social groups. Since behavioral inferences from the plowzone data fit nicely with those derived from architectural data, it is possible to proceed to the second goal of this chapter: to determine whether the discrepancy or economic hypothesis better accounts for changes in the arrangement and use of architectural space at the Phase 2-Phase 3 boundary.

7.4 Causes of Change at The Clifts

As we saw at the close of Chapter 5 (Section 5.4.7), there are two routes to discriminating between these hypotheses. The first is based on developing expectations for temporal patterning in variant trajectories based on consequence laws. The second revolves around source-law based arguments that specify which cultural variants should be favored under the two sorting mechanisms.

7.4.1 Consequence Laws and Temporal Patterns

Recall that the discrepancy hypothesis invokes learning rules that directly bias cultural transmission in favor of plans that minimize contact between owners and laborers as a function of cultural difference between the two groups. Hence we can expect temporal coincidence between changes in the layout and use of architectural space and change in the character of the labor force in the region. Menard's (1975) influx of Irish and poor English servants dates to the last quarter of the century and the massive, direct importation of slaves from Africa dates to the 1680's and 1690's. If these region-wide changes affected the layout and use of space at The Clifts, the effects are undetectable in the data for Phase 2. Although the precision of burial dating at the site leaves much to be desired, the evidence points to the change from a predominantly English or Irish labor force to a predominantly African one at the Phase 2-Phase 3 boundary, c. 1705. This coincides with the major alterations in the organization of production at the site. Based on considerations of timing alone, the notion that architectural changes at The Clifts were a learning-rule mediated response to changes in the composition of the labor force at the site cannot be rejected. However, timing is only part of the story.

Under the economic hypothesis, the timing of architectural changes might or might not be related to shifts in the racial composition of the labor force. Instead the crucial factor that initiates sorting of variant means of organizing production is economic stress. The hypothesized mechanism consists of learning rules indirectly biasing cultural transmission against variants that cause lowered rates of resource acquisition for owners. Here we can expect symptoms of economic failure on plantations following outmoded production strategies and, in extreme cases, replacement of one set of owners by another practicing more successful strategies. The earlier discussion of house-plan variation in the Chesapeake revealed the core of the dwelling at The Clifts to have had at its construction in 1670 two characteristics (a half-unit room and three units) that were being sorted against for much of the century. Hence if economic failure and planter replacement were important components of the processes affecting architectural repertoires at the end of the century, The Clifts is a likely site at which to observe them. First, consider owner replacement.

Owner replacement is a special case of migration (Section 3.1.4) in which the coefficient governing the representation of the donor population in the recipient population is unity. Thus the expectations for temporal patterning under migration apply (Section 4.1.3). In simple situations, recognizing migration depends upon the existence of stylistic differences between donor and recipient populations that, in conjunction with movement, cause punctuation or directional changes in stylistic variant frequencies. In general the pattern of stylistic change should be continuous before the process begins and after equilibrium is reached. In the special

Table 7.4 Bore diameters of white-clay pipe stems in stratified deposits. Ranks are from the occurrence seriation (Table 6.2).

PROVENIENCE	9/64	8/64	7/64	6/64	5/64	4/64	TOTAL	MEAN	RANK
PIT 346A-D			6				6	7.0	3
PIT 290A-D		6	2	1			9	7.6	4
PIT 289A-D	6	22	100	12	2		142	7.1	4
PIT 305A-G	1	15	20	5			41	7.3	5
PIT 273A-C		5	9	2			16	7.2	6
PITS 274AB,EG	1	3	6	4	1		15	6.9	6
PALISADE	1	14	21	5	0		41	7.3	6
PIT 250D-E	1	5	9	6	2		23	6.9	7
STRUCTURE 3	2	11	15	3	2		33	7.2	7
S1 REPAIRS 2-5	1	14	21	9	4		49	7.0	7
CELLAR 262AB		2	6	10	13		31	5.9	8
PIT 255F-Y		1	3	34	38		76	5.6	8
PIT 240F-G				2	6		8	5.3	8
FENCE DITCHES		24	28	45	59		156	6.1	9
PIT 288S-AD		3	13	25	22		63	6.0	10
PIT 255A-E		4	5	114	552	2	677	5.2	10
PIT 277A-C				8	19		27	5.3	11
PIT 345A-C				7	7	1	15	5.4	11
S 16 CELLAR 365A-H		1		53	195	1	250	5.2	12
POST & RAIL FENCE		3	8	18	47		76	5.6	13
PIT 280A-H			4	40	90	1	135	5.3	14
PRIVY 231DE		2	1	9	21	1	34	5.5	14
CELLAR 269A-F	1	3	18	37	60	2	121	5.7	14
S3 CELLAR 283B-M		11	31	298	927	55	1322	5.3	14
TOTAL	16	168	354	767	2074	63	3442		

case considered here, equilibrium is instantaneous. Replacement will be manifest as a sudden punctuation in stylistic variant frequency.

The existence of differential resource access among labor owners offers a second means to identify replacement, one based on differences in wealth levels. The argument is analogous to that offered in connection with identifying areas within the site used by laborers and owners. Differences in resource access cause deterministic sorting to favor different variants in two groups as a function of differences in the costs of incorporating them into behavioral phenotypes (Section 4.4.1). Can such changes be detected at The Clifts at the Phase 2-Phase 3 boundary? Examination of patterns of change in pipestem bore diameters and ceramic assemblage composition indicates that they can.

Consider first pipe-bore diameters. The evolutionary forces responsible for the decline in pipe bore diameters, first documented by Harrington (1954), over the course of the 17th and 18th centuries are unclear. One possibility is drift, abetted by indirect transmission and simple indirect bias. A second is direct bias driven by physiological preference for cooler smoke offered by longer pipes with smaller bores. In either case, synchronic group-specific differences can be expected as a result of either drift or differences in acquisition costs. If the secular process was driven by drift, it can be expected to have taken slightly different courses in different social groups within a larger population. If it was driven by direct bias, the value of the bias parameter was so small that drift would cause departures from the expected synchronous change in local groups and lead to differences among them. Both causes of the trend are also compatible with the possibility that between-group differences will arise as a result of cost differences

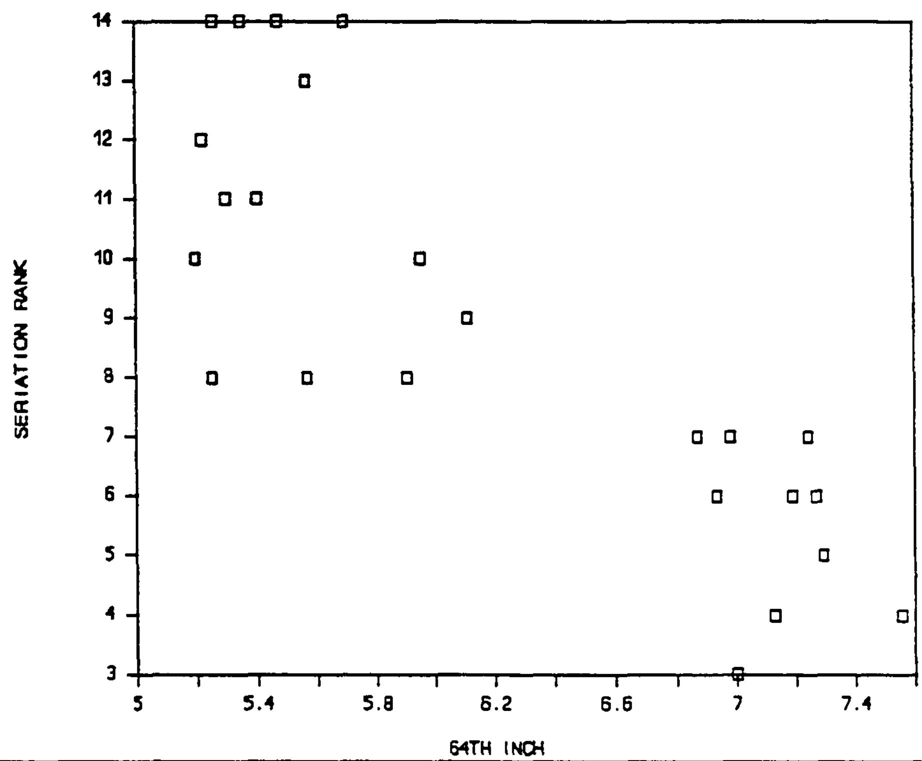


Figure 7.19 Pipestem bore diameter means plotted against their assemblage temporal ranks derived from occurrence seriation.

associated with pipes of different lengths and biased transmission favoring shorter pipes among groups with limited access to resources. On any of these models, punctuation in bore diameters imply that different groups, characterized by either distinctive stylistic repertoires or wealth levels, are being sampled. A continuous pattern of change indicates continuity in the sampled groups. Frequencies of white-clay pipestems in 64th-inch increments were tabulated for each of the provenience units included in the occurrence seriation (Table 7.4). From these, mean bore diameters for each pipestem assemblage can be computed. Plotting means against the temporal ranks of the assemblages based on the occurrence seriation reveals a sharp punctuation between ranks 7 and 8. This is precisely the boundary between Phases 2 and 3.

Next consider change through time in the composition of ceramic assemblages. Here we encounter a problem in deriving accurate estimates of ceramic-type frequency because of small sample sizes. There is a tradeoff between how fine grained the artifact classification is and the number of assemblages that can be included in the analysis. Increasing the number of types means that the assemblage contents of temporally adjacent deposits must be lumped together to derive accurate estimates of relative frequency within the types. On the other hand, decreasing the number of types increases the number of assemblages that can be considered. One solution to this dilemma is to employ two classifications, one with few types that can be applied in a fine-grained temporal analysis, the other incorporating many types and requiring considerably more assemblage aggregation.

The fine-grained temporal analysis was executed as follows. Counts of sherds from the deposits included in the occurrence seriation were assigned to one of eight classes (Table 7.5). These categories lump together the traditional ware types that have been used in the analysis of plowzone artifact distributions. Six of the categories are fine earthenwares and stoneware. The inclusion of Table Glass means that the analysis is sensitive to the prevalence of clear-glass drinking vessels, including both stemmed and non-stemmed vessels. In an attempt to capture shifts in frequencies of ceramics and glass vessels relative to vessels in pewter or wood that are not represented in the archaeological record, coarse earthenwares were included in the analysis (Beaudry et al.

Table 7.5 Sherd frequencies for seven ceramic classes and Table Glass in seriated assemblages.

PROVENIENCE	CODE	PHASE	1	2	3	4	5	6	7	8	TOTAL
PIT 346A-D	A	1	1							4	5
PIT 290A-D	A	1								10	10
PIT 289A-D	A	1	5		18					89	112
PIT 305A-G	B	1	12		10					42	64
273A-C	C	2	4	7	8					29	48
PITS 274AB,EG	C	2	2	3	1					3	9
PALISADE	D	2	12	3	4					18	37
PIT 250D-E	E	2	9	5	5				4	17	40
STRUCTURE 3	F	2	3	3	30				1	27	45
S1 REPAIRS 2-5	G	2	29	6	23				5	39	102
CELLAR 262AB	H	3	1		3	4			13	4	25
PIT 255F-Y	H	3	15	1	2	1			3	6	28
PIT 240F-G	H	3	13	2	1	1			2	8	27
FENCE DITCHES	I	3	5	1	4		2		2	9	23
PIT 288S-AD	I	3	7	4	1	5	2		5	7	31
PIT 255A-E	J	3	53	9	15	9	3		104	73	266
PIT 277A-C	K	4	12			16	1	4	0	2	35
PIT 345A-C	K	4	14			3	1	1	10	10	39
S 16 CELLAR 365A-H	L	4	6	4		3	2	2	16	6	39
POST & RAIL FENCE	L	4	18	3	1	1	0	3	9	9	44
PIT 280A-H	M	4	79	19		30	26	20	21	34	229
PRIVY 231DE	M	4	28	7	6	7	1	4	2	20	75
CELLAR 269A-F	N	4	67	14	21	11	12	1	52	20	198
S3 CELLAR 283B-N	O	4	424	86	100	160	83	65	238	157	1313

KEY TO TYPES: 1) Tin-Glazed Earthenware. 2) Staffordshire Slip Earthenware (Brown and Yellow). 3) Other Slip-Decorated Fine Earthenware (North-Devon Sgraffito, Northern-Holland, New-England). 4) English Brown Stoneware (Staffordshire Brown and Burslem-Nottingham). 5) Rhenish Blue-Gray Stoneware, 6) White Stoneware. 7) Table Glass. 8) Coarse Earthenware (Morgan Jones, Black Glazed and Buckley, North Devon, etc.).

1983, Martin 1989). The assumption is that during the occupation there was little change in use frequency per person of bulk-processing, cooking, and storage activities associated with these vessels. If this is true, then coarse earthenwares serve as a useful baseline against which to estimate changes in the use frequencies on fine earthenwares, stoneware, and glass against unrepresented vessels in other materials. Even with only eight types, it is necessary to increase sample sizes by combining smaller assemblages that occur adjacent to one another in the occurrence seriation. This results in 15 samples covering the temporal span of the occupation (A-O in Table 7.5).

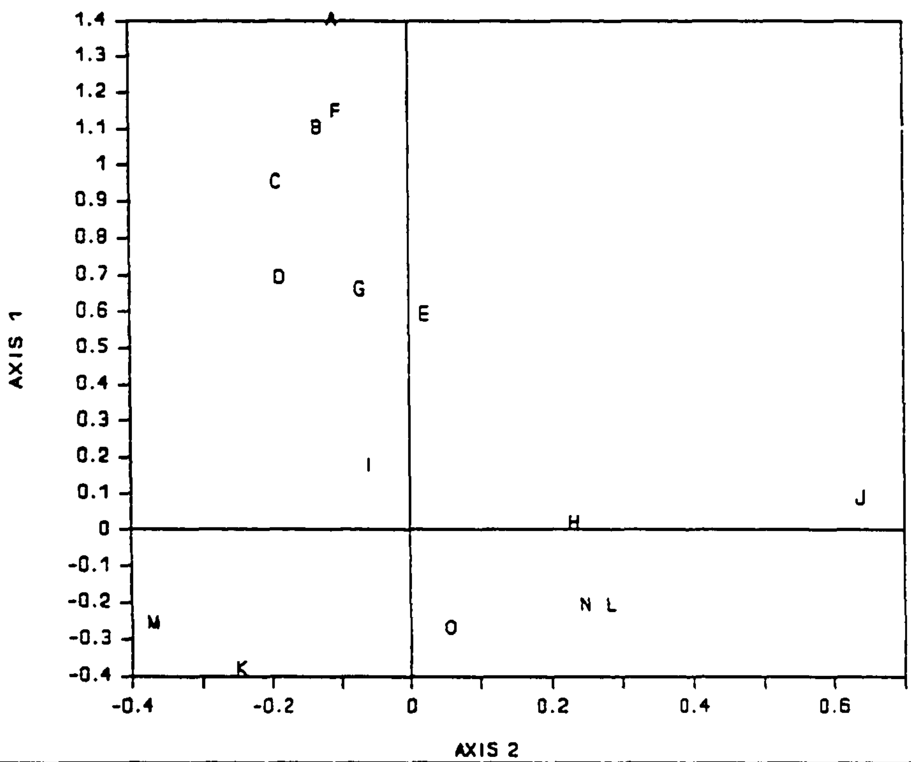


Figure 7.20 Scores of assemblage groups on the first two axes from correspondence analysis of sherd frequencies. For symbols see Table 7.5.

Correspondence analysis is a suitable technique with which to portray the similarities among assemblages in two dimensions. The first two axes to emerge from the analysis account respectively for 63% and 17% of the inertia in the data. A plot of the assemblage scores on the first two axes reveals a pattern of variation through time with both expected and unexpected components (Figure 7.20). The Phase-1 and Phase-2 assemblages are evenly spaced along a smooth curve, precisely the pattern to be expected under the drift hypothesis (Section 4.2.5). The order of early assemblages along this curve correlates nicely with their temporal order inferred from the seriation. There is one exception. The features associated with the late Phase-2 construction of the second quarter (Structure 3, denoted by point F in Figure 7.20) fall in the Phase 1 group. Just why this happens will emerge shortly.

There is a complex punctuation at the boundary between Phases 2 and 3 (G to H). After the boundary assemblages fall into two groups, each with similar scores on the first axis and variable scores on the second. The Phase-3 assemblages fall into the first group, characterized by higher axis 1 scores, while Phase-4 assemblages, with lower axis 1 scores, fall into the second. For the second half of the occupation, the first axis has some temporal significance, since assemblage scores and phase assignments correlate. However, within the two later phases, agreement with temporal ranks from the seriation is poor. For the second half of the occupation, the second axis has some temporal significance as well: Phase-4 assemblages tend to score lower than Phase-3 assemblages. However the second axis clearly reflects another source of variation within phases.

A plot of the scores of types on the first two axes of the analysis reveals more about the sources of variation resolved by this analysis (Figure 7.21). The first axis is dominated at the high end by Coarse Earthenwares and, to a lesser extent, by Other Decorated Fine Earthenwares. At the low end of the axis lie Table Glass, Tin-Glazed and Staffordshire Earthenwares and the stonewares. Thus one source of variation

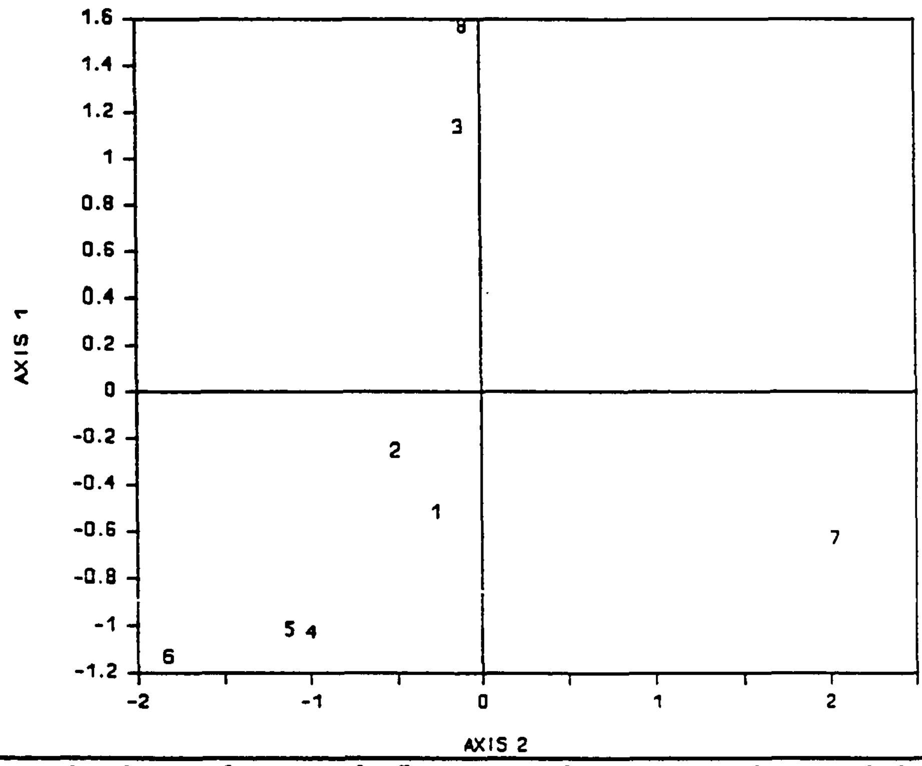


Figure 7.21 Scores of types on the first two axes from correspondence analysis of sherd frequencies. For symbols see Table 7.5.

summarized in the analysis reflects an increase in the frequency of both Table Glass and the latter ceramic groups through time. A second factor causes variation here as well. This is synchronic spatial variation related to the general-special activity gradient at the site. The anomalous position of the second quarter among Phase-1 assemblages is a reflection of the fact that it was built in what had been a special-activity area whose surface ceramic scatter was dominated by coarse earthenwares, in particular Morgan Jones. The positions along the first axis of later assemblages within the Phase-3 and-Phase 4 clusters, and their lack of correspondence with temporal ranks, is caused by variation in this same gradient.

Assemblages that score high on the second axis have higher frequencies of Table Glass, while those that score low on it have higher frequencies of the stoneware. Recall from the spatial analysis of Phase-3 and Phase-4 plowzone data that high glass frequencies were characteristic of the eastern half of the dwelling. The second source of variation behind scores on the second axis is therefore spatial. Within Phases 3 and 4, variation along this axis represents spatial differentiation in the use of the dwelling. This dimension of variation is literally orthogonal to the special-general activity area gradient and to site-wide assemblage variation.

This analysis reveals that the discontinuity at the Phase 2-Phase 3 boundary has two components. The first represents the advent of the stylistic division between the eastern and western half of the dwelling documented in the plowzone data. Averaging assemblage scores within each of the two latest phases allows representation of similarity among all the assemblages without the spatial component. When this is done, the punctuation between Phases 2 and 3 is still evident. Hence in addition to the sudden appearance of the spatial component, the analysis reveals abrupt change in the composition of the site-wide assemblage, in the direction of increases in the relative frequency of Table Glass, Tin-Glazed and Staffordshire Earthenwares, and the stoneware. After the boundary, higher proportions of Table Glass characterize Phase-3 assemblages, and higher proportions of stonewares characterize Phase-4 assemblages.

The second analysis of assemblage variation is based on a fine-grained classification of ceramic vessel forms, further subdivided into four ware groups. An

Table 7.6 Minimum vessel counts for the 4 phases. Vessels are described by 4 dimensions of variation: kind of side, profile shape, kind of rim, and diameter. The traditional names for the resulting groups are from Beaudry et al. (1983).

		PROFILE				PHASE			
WARE	SIDES	SHAPE	RIM	DIA.	TRADITIONAL NAMES	1	2	3	4
Tin-Glazed	None	Flat	-	-	Plate, Dish, Saucer	2	3	12	23
Earthenware	Curved	Open	Plain	> 6"	Bowl, Punch Bowl			3	12
	Curved	Open	Plain	<=6"	Tea Bowl				7
	Curved	Open	Complex	-	Basin, Salt			5	6
	Curved	Cylinder	Plain	-	Cup, Drinking Pot, Porringer	1		5	4
	Curved	Cylinder	Complex	-	Chamber Pot, Gally Pot	1	3	7	10
	Curved	Closed	Plain	-	Jug				
	Curved	Closed	Complex	-	Bottle				
	Straight	Open	-	-	Pan				
	Straight	Cylinder	-	-	Mug		1	1	6
Stoneware	None	Flat	-	-	Plate, Dish, Saucer				2
	Curved	Open	Plain	> 6"	Bowl, Punch Bowl				
	Curved	Open	Plain	<=6"	Tea Bowl				
	Curved	Open	Complex	-	Basin				
	Curved	Cylinder	Plain	-	Cup, Drinking Pot, Porringer				3
	Curved	Cylinder	Complex	-	Chamber Pot, Butter pot			1	
	Curved	Closed	Plain	-	Jug		1	2	16
	Curved	Closed	Complex	-	Bottle	2	1		6
	Straight	Open	-	-	Pan				
	Straight	Cylinder	-	-	Mug			12	50
Other Fine	None	Flat	-	-	Plate, Dish, Saucer	1	3	6	3
Earthenware	Curved	Open	Plain	> 6"	Bowl	2	2	2	1
	Curved	Open	Plain	<=6"	Bowl				
	Curved	Open	Complex	-	Basin		1		2
	Curved	Cylinder	Plain	-	Cup, Drinking Pot, Porringer	1	5	4	16
	Curved	Cylinder	Complex	-	Chamber Pot, Butter Pot		2	1	1
	Curved	Closed	Plain	-	Jug		1	2	1
	Curved	Closed	Complex	-	Bottle			2	
	Straight	Open	-	-	Pan				
	Straight	Cylinder	-	-	Mug				6
Coarse	None	Flat	-	-	Plate, Dish, Saucer				
Earthenware	Curved	Open	Plain	> 6"	Bowl	1		1	
	Curved	Open	Plain	<=6"	Bowl				
	Curved	Open	Complex	-	Basin				
	Curved	Cylinder	Plain	-	Cup, Drinking Pot, Porringer	6		1	
	Curved	Cylinder	Complex	-	Butter Pot, Cooking Pot	6	9	6	7
	Curved	Closed	Plain	-	Pitcher	4			
	Curved	Closed	Complex	-	Bottle				1
	Straight	Open	-	-	Pan	7	5	5	16
	Straight	Cylinder	-	-	Mug				
						34	37	78	199

extensive program of crossmending across all deposits at the site allowed assignment of many sherds to individual vessels. Each reconstructed vessel was then assigned to the earliest phase in which a sherd belonging to it had been stratified. The resulting counts by phase and the classification used to generate them are given in Table 7.6. The vessel counts make possible an assessment of between-assemblage similarity that is complementary to the foregoing sherd-based analysis. The vessel classification attends nuances of difference in vessel shape that cannot be captured using the traditional ware groups. Table Glass is excluded from consideration entirely. Complementarity can be increased further by excluding coarse earthenware vessels from consideration as well.

A two-dimensional portrayal of similarities among the four assemblages was obtained by correspondence analysis (Figure 7.22). It is evident that the Phase-1 and Phase-2 assemblages are quite similar to one another. The Phase-3 assemblage is very different and the Phase-4 assemblage is about as different from the Phase-3 as the latter is from the Phase-2 assemblage. Inspection of the original data reveals where the differences lie. The two early assemblages are dominated by a variety of vessel shapes in other (non-tin-glazed) fine earthenwares. The second half of the occupation witnessed the proliferation of tin-glazed and stoneware vessels at their expense. Increases were particularly marked in the relative frequency of tin-glazed vessels in shapes that in the documentary record are associated with solid food consumption (plates and basins), and social consumption of beverages (tea bowls and punch bowls). The stoneware vessels were mugs and jugs.

This analysis once again reveals a discontinuity between Phases 2 and 3. Because of the poor temporal resolution, it is unclear whether the difference between the Phase-3 and Phase-4 assemblages represents a second discontinuity or simply an accelerated

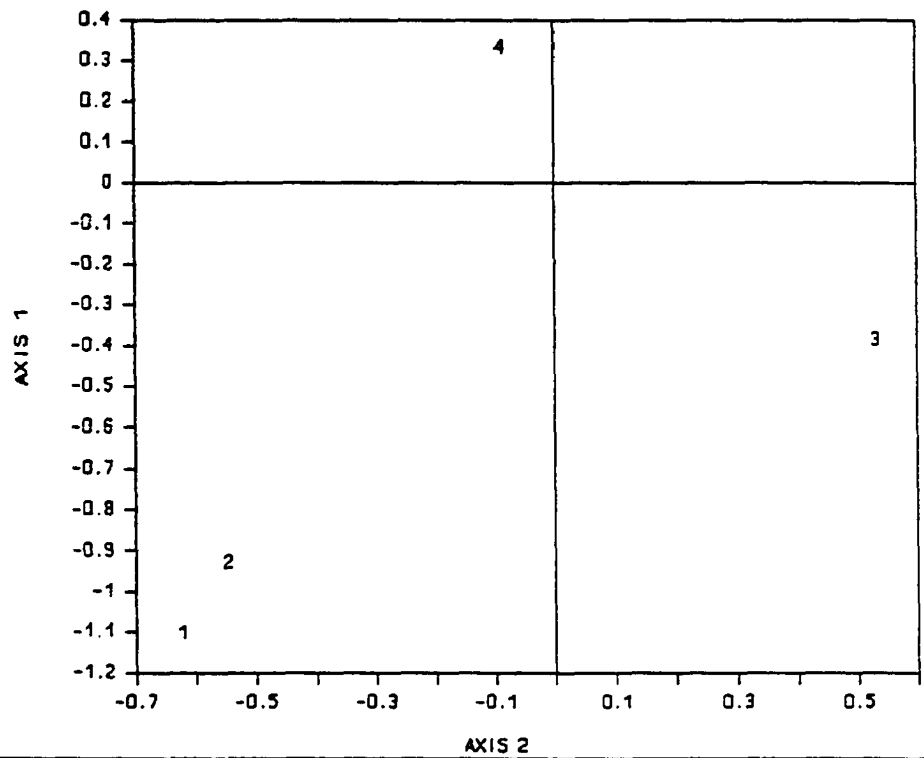


Figure 7.22 Scores of assemblages from Phases 1-4 on the first two axes from correspondence analysis of minimum vessel counts.

pace of change, relative to the first half of the occupation, within a single sequence of continuous development. The results of the sherd-based analysis lend some weight to the former alternative. It would explain why there is little variation among assemblages within Phases 3 and 4, relative to the variation between these phases.

There is, however, no ambiguity about the discontinuity between Phases 2 and 3. All three of the foregoing analyses agree on the existence of a punctuation at this time in assemblage composition at the site. It is not clear whether the punctuation is the result of sudden change in stylistic repertoires or wealth levels. Given the correlation between the two expected in complex societies (Section 4.4.2), it is likely to be a result of change in both.

The economic hypothesis is not simply about owner replacement. Rather it suggests that owner replacement is caused by economic failure. Hence the economic hypothesis would receive further support if it were possible to find evidence of contraction in wealth levels or rates of resource acquisition during the first half of the occupation, followed by sudden expansion during the second half. As we have seen, ceramic assemblage variation is an ambiguous indication of wealth levels. However, another source of evidence is not. In the tobacco economy of the early Chesapeake, wealth levels and acquisition rates were both functions of the number of laborers owned by individuals. The space requirements of the tasks performed by laborers should scale with their numbers. The space that is important is not just the amount of space in enclosed in structures, but the total amount of space regularly used in day-to-day plantation operations. How can this be measured?

Once again the functional morphological arguments that have been the basis for inferences concerning activity structure and trash disposal come into play. These have invoked individual learning rules that control the spatial location of objects and activities as a function of their interference potential. As we have seen, the distance over which a given object is removed to the site periphery from a central location is controlled by the size of the intervening area that is used on a regular basis for other purposes and the intensiveness of that usage. Measuring changes in the distance over which interfering objects were moved should offer some insights into changes in the size of the regularly

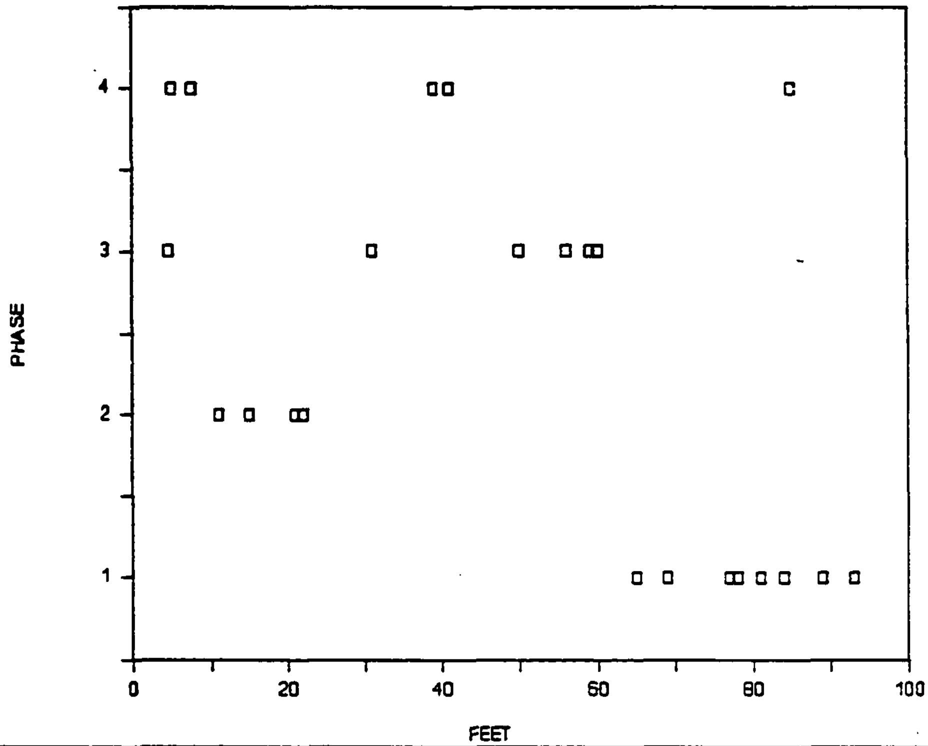


Figure 7.23 Distance between clay pits and the dwelling by phase.

used area and its correlates: the scale of plantation production and consequent wealth levels.

Clay pits, which so far have been inferentially useful to the extent their contents helped document assemblage variation, here become important in their own right. Before they were filled, these artifacts would have been obstructions to activity performance in the areas in which they were located. Hence they should be located past the edge of frequently used areas. On the other hand, since the clay that was removed from them had to be carried to the site core to be useful, there were energy payoffs for their location as close to the core as possible. Given the operation of these opposing forces, we can expect pit locations to track closely any changes in the size of the regularly used area on the site. Since the mechanisms responsible for this relationship are individual learning rules, shifts in the scale of production will be immediately reflected in shifts in pit location. Given these learning rules, expectations for temporal pattern under the economic hypothesis are explicit. A fall in the distance pits were located from the site core during the second half of the occupation should be followed by a rise at the beginning of Phase 3.

Just how far a pit was removed from the site core was measured in terms of the shortest distance between the pit edge and the nearest exterior wall of the dwelling. In a general way, temporal patterning matches the expectations developed above (Figure 7.23). High distances during Phase 1 are followed by low distances during Phase 2. There is a subsequent increase in Phase 3 and pit distance remains at these levels in Phase 4. However, two unexpected changes are evident in these data. Distances for the second half of the occupation are smaller than for Phase 1. They are also far more variable than in either Phase 1 or Phase 2. These two phenomena may be causally related.

Increased variance suggests effects from an uncontrolled variable. Given the functional-morphological arguments above, an obvious candidate is pit size. Larger pits should be located farther away from the dwelling than small ones. The variable effects of pit size on pit location are documented in Figure 7.24. Phase 1 and 2 pits are variable in size, but size has no effect on location. However, for Phase 3 and 4 pits, distance from the dwelling scales with size. Smaller pits are closer to the dwelling, larger pits are farther away. The contrast fits nicely with what we already know about changes in the

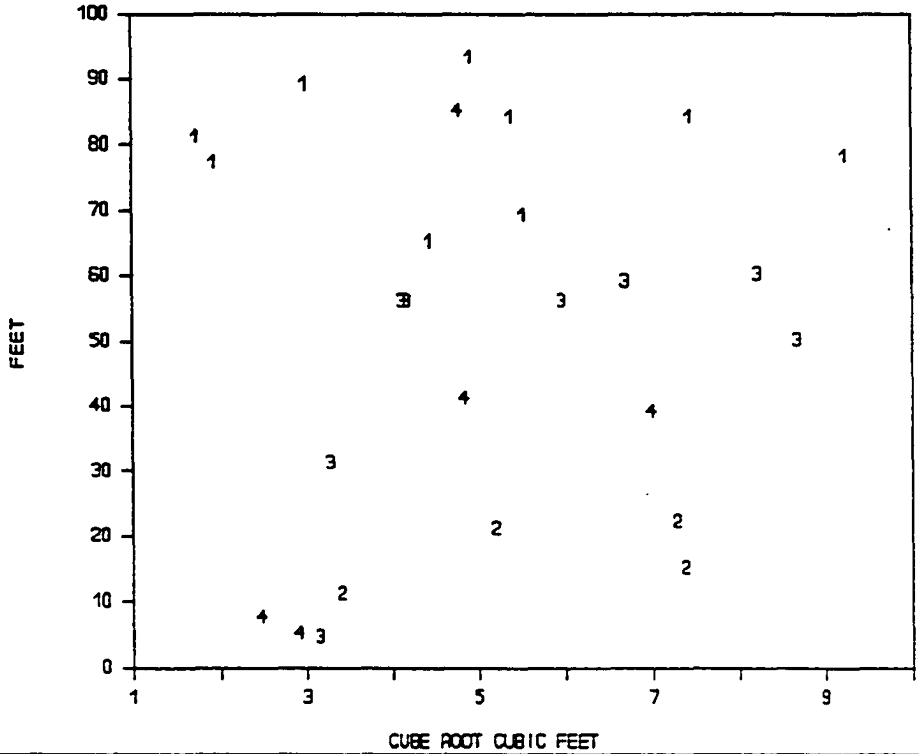


Figure 7.24 Pit distance as a function of pit size (cube-root volume) by phase.

use of space on the site, in particular the appearance of multiple outbuildings during the second half of the occupation. Although the size of yard areas shrank during the first half of the occupation, use of outdoor space during the entire period was intensive enough that even small pits were located at the site periphery. Phases 3 and 4 witnessed an expansion in the size of the regularly used area, but apparently outdoor areas were not used as intensively. Hence small pits could be dug close to the house without causing activity interference. A possible cause of decreased use intensity is a change in special-activity locations. Beginning with Phase 3, special activities which had previously been conducted outdoors were housed in outbuildings at the northern and southern edges of the site.

This analysis indicates that a substantial contraction in the scale of plantation production, and hence in the wealth level of the occupants, occurred during Phase 2. The contraction was followed by an expansion in Phase 3, after which production scale remained high for the rest of the occupation. Low resource levels during Phase 2 make it unlikely that the large outlays of resources required for massive reconstruction of the dwelling and construction of the new quarter occured during this period of the site's occupation. This is the justification for placing these events, and the deposits created by them, at the Phase 2-Phase 3 boundary, inspite of the fact that the assemblages that the deposits contain date to late Phase 2.

7.4.2 Source Laws and Favored Variants

This brings us to a brief consideration of the second means by which to discriminate between the discrepancy and economic hypotheses. This is a source-law approach devoted to the development of implications concerning the kinds of cultural variants that should be favored by deterministic sorting under each hypothesis. Concrete ideas about mechanisms allow specification of the effects that lead to their operation in certain environments and thus make it possible to anticipate which cultural variants would optimize these effects. In the case of the discrepancy hypothesis the effect responsible for sorting in favor of cultural, in this case architectural, variants is minimization of contact with laborers. Under the economic hypothesis it is minimization of costs associated with provisioning laborers and of opportunities for household resource loss caused by laborers pursuing TFT-like retaliatory strategies. The approach was explored briefly at the close of Chapter 5 where I argued that the prevalence of two-unit, direct-entry plans in the early eighteenth-century Chesapeake was an expectable result under the economic hypothesis of their superior design for surveillance of laborers and consequent prevention of household resource loss. It is worth remembering in this context that from the Phase 2-Phase 3 boundary, the dwelling at The Clifts had a two-unit, direct entry plan. The foregoing description of change in site layout at The Clifts makes it possible to apply this same approach to aspects of the arrangement and use of space that appeared with the advent of the second half of the occupation.

Both hypotheses lead us to expect the creation of a second general-activity area for laborer use, exemplified at The Clifts by the second quarter. Both hypotheses also suggest that any bulk-processing activities pursued by laborers in the dwelling would have been removed from it. These changes would have made possible less frequent contact with laborers. They also would have facilitated the implementation of inferior provisioning of laborers and lessened opportunities for access to the dwelling by laborers.

However, it is here that expectations based on the two hypotheses part company. As suggested at the close of Chapter 5, only the economic hypothesis also leads to the expectation that this change would be coincident with the appearance of multiple, separate bulk-processing and storage facilities. At The Clifts these structures fall into two size classes. The larger are multiple-bay structures, represented by Structures 13 and 14, located on the southern edge of the site. The smaller are the single-bay structures located on the northern edge. The similarity in the size of the larger buildings to the early quarter suggests that they became the sites of large-scale activities that had previously been housed in the early quarter. The large distance from the dwelling, suggests low access frequency. Processing and storage of agricultural crops are likely uses for these structures. The small size of the single-bay outbuildings, coupled with their proximity to the dwelling, indicates they become the sites of smaller-scale bulk-processing activities that had taken place in the western room of the dwelling and the quarter. Note that the multiplication of outbuildings extended beyond that favored only by differences in the scale and duration of activities. By the end of the occupation, there were two two-bay outbuildings and four single-bay ones.

Under the economic hypothesis these arrangements would have been favored because they minimized household resource loss caused by laborers. The buildings and their multiplicity allowed one-to-one mapping of laborer activities to architectural space. This minimized laborer access to resources that were not immediately related to owner-mandated task performance. It also allowed more efficient and effective surveillance of laborer activities. Individuals who were out of place could be easily identified. These developments are not expected on the discrepancy hypothesis. Minimization of contact with laborers would have been equally well served with the construction of one or two multiple-purpose outbuildings, combining bulk-processing, storage, and laborer living space. On the discrepancy hypothesis the multiplicity of outbuildings represents a waste of resources.

7.5 Conclusions

In this chapter we have seen that functional-morphological arguments based on architectural evidence and data derived from plowzone ceramic distributions at The

Clifts lead in congruent directions; directions that in a general sense are compatible with both the economic and discrepancy hypotheses. These arguments indicate that the transition to separate living areas for owners and laborers, along with the removal of all bulk-processing activities from the dwelling all date to the Phase 2-Phase 3 boundary. I have also reviewed evidence from the site with an eye to evaluating its fit with the two hypotheses. The results of this endeavor are unambiguous.

The discrepancy hypothesis offers a poor fit with the data from the Clifts. Examination of assemblage variation through time reveals that the functional changes in the layout and use of architectural space occurred in the context of population replacement. The original occupants, or individuals drawn from the same social group as the original occupants, were replaced by individuals belonging to a different segment of the Chesapeake population, differentiated in terms of style or wealth or both. This provides definitive evidence that the architectural changes at this site were not a product of directly biased learning on the part of a single, culturally homogeneous group present at the site throughout the occupation. Whatever the virtues of the discrepancy hypothesis, it does not explain what happened at this site.

The economic hypothesis fares considerably better. After an initial period of larger-scale production, the scale of plantation activities at The Clifts contracted during the economically stressful 1680's and 1690's. The contraction occurred while the site's occupants continued to use what, on the economic hypothesis, were outmoded strategies for organizing production. Contraction was severe enough to initiate abandonment of the site by this group. Additional support for the economic hypothesis is provided by the kind of functional architectural variation favored at the site during the second half of the occupation. Thus the economic hypothesis emerges from this exercise as the preferred explanation for both the architectural changes at The Clifts.

What then are the implications of these findings for the explanation of the region-wide trends documented in Chapter 5? They are ambiguous. The ambiguity arises from the fact that the detailed examination of the dynamics of stylistic and functional change has been limited to a single site. The possibility remains that the failure-replacement pattern that characterizes The Clifts is an historical accident, unique to the history of this site, lacking causal connection, and hence without wider regional significance. Elimination of this possibility must awaits the availability of observations on archaeological variability at other sites, analogous to those made at The Clifts. The required data include fine-grained chronologies, closely spaced measurements of assemblage variation, plans of plantation layouts from broad horizontal exposures, and independent evidence on the use of space that can be provided only by plowzone artifact distributions. The theoretical framework presented in the early chapters of this work provide the motivation to make such observations and the means to evaluate them. The methods developed in the last three chapters offer the tools with which those observations can be made. Until the appropriate measurements can be made at multiple sites, the matches between the deliverances of the economic hypothesis and the pattern and direction of house-plan variation through time in the region as a whole (Section 5.4.7) cannot be viewed as definitive. However, they do render the economic hypothesis a promising guide for future research.

That definitive conclusions about the Chesapeake as a whole have not been forthcoming is the result of lack of data, not of problems with the theoretical framework. Fundamental theory has done its job. It has made it possible to infer from the archaeological record a narrative of historical events, in this case at a single plantation site. In constructing those inferences, I hope to have illustrated two points made early on in this work. First, the inference of what happened and why it happened are inextricably linked. Fundamental theory is necessary to give meaning to archaeological observations and to evaluate the results. Second, evaluation of hypotheses generated under the functional-morphological approach requires building inferences on the same topic from independent sets of force and consequence laws and evaluating their agreement. This is the approach I have taken in testing inferences concerning the use of space, separately derived from architectural and plowzone evidence, against one another.

The resulting narrative is decidedly not the sort that most historians or many archaeologists would recognize. It is built around simple, mechanistic models of the forces that govern variation in the frequency of socially learned behavior in human populations. The inevitable result is that "people", conceived in the manifest image, are entirely missing. Recall, however, the arguments of the first chapter. It is only by rejecting the person-based metaphysics of the manifest image, in favor of a mechanistic account of historical process, that interpretations of the archaeological record will eventually become more than the ephemera of the latest styles of common-sense or social-science discourse.

References

Alexander, R.D.
1974 The evolution of social behavior. *Annual Review of Ecology and Systematics* 5:325-383.

1979 *Darwinism and Human Affairs*. University of Washington Press, Seattle.

Ammerman, A.J. and M.W. Feldman
1974 On the "making" of an assemblage of stone tools. *American Antiquity*. 39(4):610-615.

Ammerman, A.J. and L.L. Cavalli-Sforza
1973 A population model for the diffusion of early farming in Europe. In *The Explanation of Culture Change*, edited by C. Renfrew, pp.343-347. Duckworth, London.

1984 *The Neolithic Transition and the Genetics of Populations in Europe*. Princeton University Press, Princeton.

Andrews, C.M.
1959 *Narratives of the Insurrections: 1675-1690*. New York.

Aufderheide, A.C., F.D. Neiman, L. Witmers and G. Rapp
1981 Lead in bone II: Skeletal-lead content as an indicator of lifetime lead ingestion and the social correlates in an archaeological population. *American Journal of Physical Anthropology* 55:285-291.

Angel, J.L.
1980 Family skeletons from Stratford. In *Field Archaeology of The Clifts Plantation Site*, by F.D. Neiman, pp.222-231. Ms. on file, Robert E. Lee Memorial Association, Inc. Stratford, VA.

Axelrod, R.
1984 *The Evolution of Cooperation*. Basic Books, New York.

Axelrod, R. and W.D. Hamilton
1981 The evolution of cooperation. *Science* 211:1390-1396.

Bamforth, D.B.
1988 Investigating microwear polishes with blind tests: the Institute results in context. *Journal of Archaeological Science* 15(1):11-23.

Bandura, A.
1977 *Social Learning Theory*. Pentice Hall, Englewood Cliffs, NJ.

Barash, D.
1979 *The Whisperings Within*. Penguin, London.

Barkow, J.H.
1984 The distance between genes and culture. *Journal of Anthropological Research* 40:366-379.

Barley, M.W.
1961 *The English Farmhouse and Cottage.* Routledge and Kegan Paul, London

Barth, F. Introduction. In *Ethnic Groups and Boundaries, The Social Organization of Cultural Difference,* edited by F. Barth, pp.9-38. Little, Brown and Co., Boston.

Bateson, P.P.G.
1982 Behavioral development and evolutionary processes. In *Current Problems in Sociobiology,* edited by King's College Sociobiology Group, pp.133-51. Cambridge University Press, Cambridge.

1983 Rules for changing the rules. In *Evolution from Molecules to Men,* edited by D.S. Bendall, pp.483-507. Cambridge University Press, Cambridge.

Beaudry, M.C., J. Long, H.M. Miller, F.D. Neiman and G.W. Stone
1983 A vessel typology for early Cheaspeake ceramics. *Historical Archaeology* 17(1):18-43.

Behrenmsmyer, A.K.
1984 Taphonomy and the fossil record. *American Scientist* 72:558-566.

Behrensmeyer, A.K., K.D. Gordon and G.T. Yanigi
1985 Trampling as a cause of bone surface damage and pseudo-cutmarks. *Nature* 319:768-771.

Behrensmeyer, A.K., and D.E. Schindel
1983 Resolving time in paleobiology. *Paleobiology* 9(1):1-8.

Benzecri, J.P.
1969 Statistical analysis as a tool to make patterns emerge from data. In *Methodologies of Pattern Recognition,* edited by S. Wanatabi, pp.35-60. Academic Press, New York

Betzig, L.
1986 *Despotism and Differential Reproduction: A Darwinian View of History.* Aldine, New York.

Betzig, L., M. Borgerhoff Mulder, and P. Turke (eds.)
1988 *Human Reproductive Behavior: A Darwinian Perspective.* Cambridge University Press.

Binford, S.R. and L.R. Binford
1968 Archaeological theory and method. In *New Perspectives in Archaeology*, edited by S.R. Binford and L.R.Binford, pp.1-3. Aldine Publishing Company, Chicago.

Binford, L.R.
1962 Archaeology as anthropology. *American Antiquity* 28(2):217-225.

1965 Archaeological systematics and the study of culture process. *Americam Antiquity* 31:203-210.

1971 *An Archaeological Perpective*. Academic Press, New York.

1978 Dimensional analysis of behavior and site structure: learning from an Eskimo hunting stand. *American Antiquity* 43(3):330-361.

1977 General introduction. In *For Theory Building in Archaeology, Essays in Faunal Remains, Aquatic Resources, Spatial Analysis and Systemic Modelling*, edited by L.R. Binford, pp. 1-10. Academic Press, New York.

1981a Behavioral archaeology and the Pompeii premise. *Journal of Anthropological Research* 37(3):195-208.

1981b *Bones, Ancient Men and Modern Myths*. Academic Press, New York.

1982 Objectivity - Explanation - Archaeology, 1981. In *Theory and Explanation in Archaeology*, edited by Colin Renfrew, Michael J. Rowlands and Barbara Abbott Seagraves, pp. 125-138. Academic Press, New York.

1983 *In Pursuit of the Past*. Thames and Hudson, London.

1986 In pursuit of the future. In *American Archaeology Past and Future*, edited by D.J. Meltzer, D.D. Fowler and J.A. Sabloff, pp. 459=479. Smithsonian Institution Press, Washington, D.C.

1987 Researching ambiguity: Frames of reference and site structure. In *Method and Theory in Activity Area Research*, edited by Susan Kent, pp. 449-512. Columbia University Press, New York.

1989 Styles of style. *Journal of Anthropological Archaeology* 8:51-67.

Binford, L.R. and S.R. Binford
1966 A preliminary analysis of functional variability in the Mousterian of Levallois facies. *American Anthropologist* 68(2):238-295

Blurton Jones, N.J.
1986 Bushman birth spacing: A test for optimal interbirth intervals. *Ethology and Sociobiology* 7:91-106.

Boehm, C.
1978 Rational preselection from Hamadryas to *Homo sapiens*. *American Anthropologist* 80:265-296.

Bolvekin, E., E. Helskog, K. Helsokog, I.M. Holm-Olsen, L. Solheim, and R. Bertelsen.
1982 Correspondence analysis: an alternative to principal components. *World Archaeology* 14(1):40-60.

Bonner, J.T.
1980 *The Evolution of Culture in Animals*. Princeton University Press, Princeton.

Borgerhoff Mulder,M.
1987a Adaptation and evolutionary approaches to anthropology. *Man* 22:25-41.

1987b On cultural and reproductive success: Kipsigis evidence. *American Anthropoologist* 89:617-634.

Bloch, M.
1983 *Marxism in Anthropology*. Oxford University Press, Oxford.

Boyd, Robert and Peter J. Richerson.
1985 *Culture and the Evolutionary Process*. University of Chicago Press, Chicago.

Braun, D.P.
1983 Pots as tools. In *Archaeological Hammers and Theories*, edited by J.A. Moore and A.S. Keene, pp. 107-134. Academic Press, New York.

Brown, Cynthia G.
1979 Plymoth excavations, Castle Street: the pottery. *Plymoth Museum Archaeological Series 1.*

Brush, G.S.
1986 Geology and paleoecology of Chesapeake Bay. *Journal of the Washington Academy of Sciences* 76(3):146-160.

Buchanan, W.T. and E.F. Heite
1971 The Hallowes Site: A seventeenth-century yeoman's cottage in Virgina. *Historical Archaeology* 5:38-48.

Buikstra, J.E., L. Konigsburg and J. Bullington
1986 Fertility and the development of agriculture in the Midwest. *American Antiquity* 51:528-546.

Burrough, P.A.
1983 Multiscale spatial variation in soil.II A non-Brownian fractal model and its application in soil survey. *Journal of Soil Science* 34:599-620.

Campbell, D.T.
1965 Variation and selection in cultural evolution. In *Social Change in Developing Areas: a Reinterpretation of Evolutionary Theory*, edited by H.R. Barringer, G.I.Blaksten and R.W.Mack, pp.19-49. Schenckman, Cambridge.

1974 Evolutionary epistemology. In *The Philosophy of Karl Popper, Volume 1*, edited by P. Schlipp, pp. 413-463. Lasalle, Open Court.

Caro, T.M. and M. Bogerhoff Mulder
1987 The problem of adaptation in the study of human behavior. *Ethology and Sociobiology* 8:61-72.

Carr, L.G.
1974 The metropolis of Maryland. *Maryland Historical Magazine* 69(2):124-145.

Carr, L.G. and R.R. Menard
1979 Immigration and opportunity, the freedman in early colonial Maryland. In *The Chesapeake in the Seventeenth Century: Essays on Anglo-American Society*, edited by T.W. Tate and D.L. Ammerman, pp. 206-242. University of North Carolina Press, Chapel Hill.

Carr, C.
1984 The nature of organization of intrasite archaeological records and spatial analytic approches to their investigation. *Advances in Archaeological Method and Theory* 7:103-222.

Carson, C.
1974 The "Virginia House" in Maryland. *Maryland Historical Magazine* 69: 185-196.
1976 Segregation in vernacular buildings. *Vernacular Architecture* 7:24-29.

1978 Doing history with material culture. In *Material Culture and the Study of American Life*, edited by I.M.G. Quimby, pp.41-65. W.W. Norton, New York.

Carson, C., N.F. Barka, W.M. Kelso, G.W. Stone, and D. Upton
1981 Impermanent architecture in the southern American colonies. *Winterthur Portfolio* 16(2-3):135-196.

Cassagrande, J.B., S. Thompson and P. Young
1964 Colonization as a research frontier. In *Process and Pattern in Culture, Essays in Honor of Julian H. Steward*, edited by R.A. Manners, pp. 281-325. Aldine, Chicago.

Cavalli-Sforza, L.L. and M.W. Feldman
1981 *Cultural Transmission and Evolution*. Princeton University Press, Princeton.

1983 Cultural vs. genetic adaptation. *Proceedings of the National Academy of Sciences* 80:4993-4996.

Chagnon N. and W. Irons, eds.
1979 *Evolutionary Biology and Human Social Behavior: an Anthropological Perspective*. Duxbury, North Scituate, MA.

Cocke, C.F.
1960 *Parish Lines, Diocese of Southwestern Virginia*. Virginia State Library, Richmond

1964 *Parish Lines, Diocese of Southern Virginia*. Virginia State Library, Richmond

1967 *Parish Lines, Diocese of Virginia*. Virginia State Library, Richmond

Cosmides, L.
1989 The logic of social exchange: Has natural selection shaped human reason? Studies in the Watson selection task. *Cognition* 31(3):187-276.

Cosmides, L. and J. Tooby
1987 From evolution to behavior: Evolutionary Psychology as the missing link. In *The Latest on the Best, Essays on Evolution and Optimality*, edited by John Dupre, pp.277-306. MIT Press, Cambridge

1989 Evolutionary psychology and the generation of culture, Part II, Case study: A computation theory of social exchange. *Ethology and Sociobiology* 10:51-97.

Cotterell, B. and J. Kamminga
1987 The formation of flakes. *American Antiquity* 52(4):675-708.

Craven, F.W.
1971 *White, Red, and Black: The Seventeeth-Century Virginian*. University of Virginia Press, Charlottesville.

Crow, J.F.
1986 *Basic Concepts in Population, Quantitative and Evolutionary Genetics*. W.H. Freeman, San Francisco.

Crow, J.F. and M. Kimura
1970 *An Introduction to Population Genetics Theory*. Harper Row, New York.

Cummings, A.L.
1979 *The Frame Houses of Massachusetts Bay, 1625-1675*. Harvard University Press, Cambridge.

Davis, J.C.
1986 *Statistics and Data Analysis in Geology*. John Wiley, New York

Dawkins, R.
1982 *The Extended Phenotype*. W.H. Freeman, San Fransisco.

Deal, M. Household pottery disposal in the Maya Highlands: an ethnoarchaeological interpretation. *Journal of Anthropological Archaeology*. 4:243-291.

De Boer, W.R. and D.W. Lathrap
1979 The making and breaking of Shipibo-Conibo ceramics. In *Ethnoarchaeology: Implication of Ethnography for Archaeology*, edited by Carol Kramer, pp. 102-138. Columbia University Press, New York.

Deetz, J.F.
1967 *Invitation to Archaeology*. Natural History Press, New York.

1988 American historical archaeology: methods and results. *Science* 239:362-367.

Dickemann, M.
1979 Female infanticide, reproductive strategies and social stratification: a preliminary model. In *Evolutionary Biology and Human Social Behavior: An Anthropological Perspective*, edited by N. Chagnon and W. Irons, pp.321-367. Duxbury, North Scituate MA.

Domjan, M.
1980 Ingestional aversion learning: unique and general processes. In *Advances in the Study of Behavior* 11:275-336.

Doran, J.E. and F.R. Hodson
1975 *Computers and Mathematics in Archaeology*. Harvard University Press, Cambridge.

Dunbar, R.I.M.
1988 *Primate Social Systems*. Cornell University Press, New York.

Dunnell, R.C.
1970 Seriation method and its evaluation. *American Antiquity* 53:305-319.

1971 *Systematics in Prehistory*. Free Press, New York.

1978a Style and function: a fundamental dichotomy. *American Antiquity* 43(2):192-202.

1978b Archaeological potential of anthropological and scientific models of function. In *Archaeological Essays in Honor of Irving B. Rouse*, edited by R.C. Dunnell and E.S. Hall, Jr.,pp.41-73. Mouton, The Hague.

1980 Evolutionary theory in archaeology. *Advances in Archaeological Method and Theory* 3:35-99.

1982 Science, social science, and common sense: the agonizing dilemma of modern archaeology. *Journal of Anthropological Research* 38(1):1-25.

1986a Five decades of American archaeology. In *American Archaeology Past and Future*, edited by D.J. Meltzer, D.D. Fowler and J.A. Sabloff, pp. 23-49. Smithsonian Institution Press, Washington, D.C.

1986b Methodological issues in Americanist archaeological clssification. *Advances in Archaeological Method and Theory* 9:149-207.

Durham, W.H.

1981 Overview: optimal foraging analysis in human ecology. In *Hunter-gatherer foraging strategies: ethnographic and archaeological analyses*, edited by B. Winterhalder and E.A. Smith, pp.218-221. University of Chicago Press.

1982 Interaction of genetic and cultural evolution: models and examples. *Human Ecology* 10:289-323.

Earle, C.V.

1975 The evolution of a Tidewater settlement system, All Hallow's Parish, Maryland, 1650-1783. *University of Chicago, Department of Geography, Research Paper 170.*

1979 Environment, disease, and mortality in early Virginia. In *The Chesapeake in the Seventeenth Century: Essays on Anglo-American Society,* edited by T.W. Tate and D.L. Ammerman, pp. 96-125 University of North Carolina Press, Chapel Hill.

Earle, T.

1987 Specialization and the production of wealth: Hawaiian cheifdoms and the Inka empire. In *Specialization, Exchange, and Complex Societies,* edited by E. Brumfield and T. Earle, pp.64-75. Cambridge University Press, Cambridge.

Eden, P.

1969 Smaller post-medieval houses in eastern England. In *East Anglian Studies*, edited by L.M. Munby, pp.71-93.

Emerson, M.C.
1988 *Decorated Clay Tobacco Pipes from the Chesapeake.* Ph.D. Dissertation, Department of Anthropology, University of California, Berkeley.

Essock-Vitale, S. and R.M. Seyfarth
1987 Intelligence and social cognition. In *Primate Societies,* edited by B.B. Smuts, D.L. Cheney, R.M. Seyfarth, R.W. Wrangham and T.S. Struhsaker, pp 452-461. University of Chicago Press, Chicago.

Feathers, J.K.
1989 Effects of temper on strength of ceramics: response to Bronitsky and Hamer. *American Antiquity* 54: 579-588.

Feinman, G.M., S. Upham and K.B. Lightfoot
1981 The production step measure: an ordinal index of labor input in ceramic manufacture. *American Antiquity* 46:871-884.

Fiske, D.W. and R.A. Schweder (eds.)
1986 *Metatheory in Social Science.* Unversity of Chicago Press, Chicago.

Flinn, M.V. and R.D. Alexander
1982 Culture theory: The developing synthesis from biology. *Human Ecology* 10:383-400.

Ford, J.A.
1954 The type concept revisited. *American Anthropologist* 56:42-54.

Fox, C.
1932 *The Personality of Britain.* National Museum of Wales, Cardiff.

Galef, B.G.
1976 Social transmission of acquired behavior: a discussion of tradition and social leanring in vertebrates. *Advances in the Study of Behavior* 16:77-100.

Galenson, D.W.
1981 *White Servitude in Colonial America: An Economic Analysis.*Cambridge University Press, Cambridge.

Gergen, Kenneth J.
1986 Correspondence versus autonomy in the language of understanding human action. In *Metatheory in Social Science,* edited by Donald W. Fiske and Richard A. Schweder, pp. 136-162. Unversity of Chicago Press, Chicago.

Gifford, Diane G.
1981 Taphonomy and paleoecology, a critique of archaeology's sister disciplines. *Advances in Archaeological Method and Theory* 4:365-438.

Gilman, P.A.
1987 Architecture as artifact: Pit structures and pueblos in the American Southwest. *American Antiquity* 52(3):538-64).

Glaser, J.D.
1968 Coastal Geology of Southern Maryland. *Maryland Geological Survey Guidebook 1.*

Gould, Richard and Patty Jo Watson
1982 A dialogue on the meaning and use of analogy in ethnoarchaeological reasoning. *Journal of Anthropological Archaeology* 1:355-381.

Gould, S.J.
1986 Evolution and the triumph of homology, or why history matters. *American Scientist 74:60-69.*

Gould, S.J. and R.C. Lewontin
1979 The Spandrels of San Marco and the Panglossian paradigm: a critique of the adaptationist programme. *Proceedings of the Royal Society of London* 205:581-589.

Gould, S.J., D.M. Raup, J.J. Sepkoski, Jr., T.J.M. Schopf, D.S. Simberloff
1986 The shape of evolution: a comparison of real and random clades. *Paleobiology* 3:23-40.

Grayson, D.K.
1986 Eoliths, archaeological ambiguity and the gereation of "middle-range" research. In *American Archaeology Past and Future*, edited by D.J. Meltzer, D.D. Fowler and J.A. Sabloff, pp. 77-134. Smithsonian Institution Press, Washington, D.C.

Greenacre, M. and T. Hastie
1987 The geometry of correspondence analysis. *Journal of the American Statistical Association* 82:437-447.

Greenacre, M. and E. Vrba
1984 Graphical display and interpretation of antelope census data in African wildlife areas using correspondence analysis. *Ecology* 65:984-997.

Harpending, H., A. Rogers and P. Draper
1987 Human Sociobiology. *Yearbook of Physical Anthropology* 30:127-150.

Harrington, J.C.
1954 Dating stem fragments of seventeenth and eighteenth century clay tobacco pipes. *Quarterly Bulletin of the Archaeological Society of Virginia* 9(1):9-13.

Harris, M.
1979 *Cultural Materialism: The Struggle for a Science of Culture*. Random House, New York.

Hatch, C.
1957 *The First Seventeen Years: Virginia 1607-1624.* Virginia 350th Anniversary Settlement Corporation, Willamsburg, VA.

Heikkenen, H.J. and M.R. Edwards
1983 The key-year dendrochronology technique and its application in dating historic structures in Maryland. *Bulletin, Association for Prevservation Technology* 25(3):3-25.

Henry, S.L.
1979 Terra-cotta tobacco pipes in 17th-century Virginia and Maryland. *Historical Archaeology* 13:14-37.

Hesse, Mary
1978 Theory and value in the social sciences. In *Action and Interpretation: Studies in the Philosophy of the Social Sciences*, edited by C. Hookway and P. Pettit, pp.1-16. Cambridge University Press, Cambridge.

Hewlett, and L.L. Cavalli-Sforza
1986 Cultural transmission among Aka Pygmies. *American Anthropologist* 88:922-934.

Hill, K., H. Kaplan, K. Hawkes and M. Hurtado
1987 Foraging decisions among Ache hunter-gatherers: New data and implications for optimal foraging models. *Ethology and Sociobiology* 8:1-36.

Hill, J.
1984 Prestige and reproductive success in man. *Ethology and Sociobiology* 5:77-95.

Hill, M.O.
1973 Reciprocal averaging: an eigenvector method of ordination. *Journal of Ecology* 61:237-251.

1974 Correspondence analysis: a neglected multivariate technique. *Applied Statistics* 23:340-354.

Hinde, R.A. and J. Fisher
1951 Further observations on the opening of milk bottles by birds. *British Birds* 44:393-96.

Hitchcock, R.
1987 Sedentism and site structure organization in Kalahari Basarwa residential locations. In *Method and Theory in Activity Area Research*, edited by S. Kent, pp.374-423. Cambridge University Press, New York.

Hodder, Ian
1986 *Reading the Past*. Cambridge University Press, Cambridge.

1987 Comment on Leone et al. 1987. *Current Anthropology* 28(3):295.

Horn, J.
1979 Servant emigration to the Chesapeake in the Seventeenth Century. In *The Chesapeake in the Seventeenth Century: Essays on Anglo-American Society*, edited by T.W. Tate and D.L. Ammerman, pp. 51-95. University of North Carolina Press, Chapel Hill.

Houston, A., C. Clark, J. McNamara,and M. Mangel
1988 Dynamic models in behavioral and evolutionary ecology. *Nature* 332:29-34.

Hull, David
1980 Individuality and selection. *Annual Review of Ecology and Systematics* 11:311-332.

1982 The naked meme. In *Learning, Development and Culture, Essays in Evolutionary Epistemology*, edited by H. Plotkin, pp.273-330. John Wiley and Sons, Chichester.

1983 Karl Popper and Plato's Metaphor. *Advances in Cladistics* 2:177-190.

Humphrey, N.K.
1976 The social function of intellect. In *Growing Points in Ethology*, edited by P.P.G. Bateson and R.A. Hinde. Cambridge University Press, Cambridge.

Hurcombe, Linda
1988 Some criticisms and suggestions in response to Newcomer et al. 1986. *Journal of Archaeological Science* 15(1)1-10.

Irons, W.
1979 Natural selection, adaptation and human social behavior. In *Evolutionary Biolohgy and Human Social Behavior: An Anthropological Perspective*, edited by N. Chagnon and W. Irons, pp.257-272. Duxbury, North Scituate, MA.

Johnson, I.
1984 Cell frequency recording and analysis of artifact distributions. In *Intrasite Spatial Analysis in Archaeology*, edited by H. Hietala, pp. 75-96. Cambridge University Press, Cambridge.

Johnson, M.W.
1989 Conceptions of agency in archaeological interpretation. *Journal of Anthropological Archaeology* 8:189-211.

Johnston, T.D.
1981 Contrasting approaches to a theory of learning. *Behavioral and Brain Sciences* 4:125-73.

Jolly, A.
1966 Lemur social behvior and primate intelligence. *Science* 153:501-506.

Kawai, M.
1965 Newly-acquired pres-cultural behavior of the natural troop of Japanese monkeys on Koshina Islet. *Primates* 6:1-30.

Keeler, R.W.
1978 *The Homelot on the Seventeenth Century Chesapeake Tidewater Frontier.* Ph.D. Dissertation, Department of Anthrpology, University of Oregon.

Keeley, L.
1980 *Experimental Determination of Stone Tool Uses: a Microwear Analysis.* University of Chicago Press, Chicago.

Kelso, W.M.
1984 *Kingsmill Plantations, 1619-1800: Archaeology of Country Life in Colonial Virgina.* Academic Press, Orlando.

Kelso, W.M. and E.A. Chappell
1974 Excavation of a seventeenth-century pottery kiln, Westmoreland County, Virginia. *Historical Archaeology* 8:53-63.

Kendall, D.G.
1963 A statistical approch to Flinders Petrie's sequence-dating. *International Statistical Institute Bulletin* 40:657-680.

1971 Seriation from abundance matrices. In *Mathematics in the Archaeological and Historical Sciences,* edited by F.R. Hodson, D.G. Kendall, and P. Tantu, pp.215-252. University of Edinbugh Press, Edinburgh.

Kimura, M.
1983 *Neutral Theory of Molecular Evolution.* Cambridge: Cambridge University Press.

King, J.A.
1988 A comparative midden analysis of a household and inn in St. Mary's City, Maryland. *Historical Archaeology* 22(1):37-59.

King, J.A. and H.M. Miller
1987 The view from the midden: an analysis of midden distribution and variability at the Van Sweringen Site, St. Mary's City, Maryland. *Historical Archaeology* 21(2):37-59.

Kitcher, P.
1985 *Vaulting Ambition: Sociobiology and the Quest for Human Nature.* MIT Press, Cambridge.

Krebs, J.R and N. Davies
1981 *An Introduction to Behavioural Ecology.* Blackwell, Oxford.

Krebs, J.R, D.W. Stephens and W.J. Sutherland
1983 Perspectives in optimal foraging. In *Persepctives in Ornithology*, edited by G.A. Clark and A.H. Brush, pp.165-216. Cambridge University Press, Cambridge.

Kroeber, A.L.
1916 Zuni potsherds. *American Museum of Natural History, Anthroplogical Papers.* 18(1).

Kuhn, T.S.
1970 *The Structure of Scientific Revolutions,* Second Edition. University of Chicago Press, Chicago.

Kurland, J.
1979 Paternity, mother's brother and huamn sociality. In *Evolutionary Biology and Human Social Behavior: an Anthropological Perspective,* edited by N. Chagnon and W. Irons, pp 145-180. Duxbury, North Scituate, MA.

Land, A.
1981 *Colonial Maryland, A History.* KTO Press, Millwood, New York.

Lebart, L., A. Morineau, and K.W. Warwick
1984 *Multivariate Descriptive Statistical Analysis, Correspondence Aanalysis and Related Techniques for Large Matrices.* John Wiley and Sons, New York.

Legendre, L. and P. Legendre
1983 *Numerical Ecology.* Elsevier Scientific Publishing, Amsterdam.

Leonard, R.D. and G.T. Jones
1987 Elements of an inclusive evolutionary model for archaeology. *Journal of Anthropological Archaeology* 6:199-219.

Leone, Mark P.
1972 Issues in anthropological archaeology. In *Contemporary Archaeology,* edited by M.P. Leone, pp. 14-27. Southern Illinois University Press, Carbondale.

Leone, Mark P. and Anne M.Palkovitch
1983 Ethnographic inference and analogy in analyzing prehistoric diets. In *The Analysis of Prehistoric Diets*, edited by R.I. Gilbert and J.H. Mielke, pp. 423-431. Academic Press, New York.

Leone, Mark P., Parker Potter and Paul A. Schackel
1987 Toward a Critical Archaeology. *Current Anthropology* 28(3):283-302.

Lewarch, D.E. and M.J. O'Brien
1981 Effect of short-term tillage on aggregate provenience surface pattern. In *Plowzone Archaeology: Contributions to Theory and Technique*, edited by M.J. O'Brien and D.E.Lewarch, pp. 7-49. Publications in Anthropology 27, Vanderbilt University.

Lewis, K.
1984 *The American Frontier: An Archaeological Study of Settlement Pattern and Process*. Academic Press, Orlando.

Lewontin, Richard C.
1974a *The Genetic Basis of Evolutionary Change*. Columbia Univerity Press, New York.

1974b Darwin and Mendel -- the materialist revolution. In *The Heritage of Copernicus:Theories Pleasing to the Mind*, edited by J. Neyman, pp.166-183. MIT Press, Cambridge.

1976 The analysis of variance and the analysis of cause. *American Journal of Human Genetics* 26:400-411.

1980 Theoretical population genetics in the evolutionary synthesis. In *The Evolutionary Synthesis*, edited by E. Mayr and W.B. Provine, pp. 58-68. Harvard University Press, Cambridge.

1982 Keeping it clean. *Nature* 300:113-114.

Lumsden, C. and E.O. Wilson
1981 *Genes, Mind, and Culture*. Harvard University Press, Cambridge.

Mack, R.N.
1985 Invading plants: their contribution to population biology. In *Studies on Plant Demography*, edited by J. White, pp.127-142. Academic Press, London.

Main. G.L.
1982 *Tobacco Colony: Life in Early Maryland, 1650-1720*. Princton University Press, Princeton.

Mainardi, D.

1980 Tradition and social transmission of behavior in animals. In *Sociobiology: Beyond Nature-Nurture?* edited by G. Barlow and J. Silverberg, pp.227-255. Westview Press, Boulder, CO.

Marks, J. and E. Staski
1988 Indivduals and the eovolution of biological and cultural systems. *Human Evolution* 3(3):147-161.

Marquardt, W.H.
1978 Advances in archaeological seriation. *Advances in Archaeological Method and Theory* 1:266-314.

Martin, A.S.
1989 The role of pewter as missing artifact: consumer attitudes toward tablewares in late 18th century Virginia. *Historical Archaeology* 23(2):1-27.

Maynard Smith, J.
1978 Optimization theory in evolution. *Annual Review of Ecology and Systematics* 9:31-56.

1982 *Evolution and the Theory of Games.* Cambridge University Press, Cambridge.

1987 When learning guides evolution. *Nature* 329:761-762.

Maynard Smith, J. and N. Warren
1982 Models of cultural and genetic change. *Evolution* 36:620-627.

Mayr, E.
1959 Typological versus population thinking. In *Evolution and Anthropology: a Centennial Appraisal,* edited by B.J. Meggars, pp.409-412. Washington Anthropological Society, Washington, D.C.

Meinguet, J.
1979 Multivariate interpolation of arbitrary points made simple. *Journal of Applied Mathematics and Physics* 30:292-304.

Meltzer, D.J.
1979 Paradigms and the nature of change in Americam archaeology. *American Antiquity* 44:644-658.

1981 A study of style and function in a class of tools. *Journal of Field Archaeology* 8(3):313-326.

1984 On stone procurement and settlement mobility in eastern fluted point groups. *North American Archaeologist* 6:1-24.

Menard, R.R.
1975 *Economy and Society in Early Colonial Maryland.* Ph.D. Dissertation, Department of History, University of Iowa.

1977 From servants to slaves: the transformation of the Chesapeake labor system. *Southern Studies* 16:355-390.

1980 The tobacco industry in the Chesapeake colonies, an interpretation. *Research in Economic History* 5:109-178.

Mercer, E.
1975 *English Vernacular Houses: A Study of Trdaitional Farmhouses and Cottages.* Her Majesty's Stationary Office, London

Miller, G.L.
1980 Classification and economic scaling of 19th-century ceramics. *Historical Archaeology* 14:1-40.

Miller, H.M.
1983 A search for the "Citty of Saint Maries". *St. Mary's City Archaeology Series 1.*

1984 *Colonization and Subsistence on the 17th-Century Chesapeake Frontier.* Ph.D. Dissertation, Department of Anthropology, Michigan State University.

Miller, D. and C. Tilley
1984 Ideology, power, and prehistory: an introduction. In *Ideology, Power, and Prehistory*, edited by D. Miller and C. Tilley, pp.1-16. Cambridge University Press, Cambridge.

Mollison, D.
1977 Spatial contact models for ecological and epidemic spread. *Journal of the Royal Statistical Society, Series B*, 39:283-326.

Morgan E.S.
1975 *American Slavery, American Freedom, The Ordeal of Colonial Vriginia.* W.W. Norton, New York.

Morrison, R. et al.
1983 *On the Map: An Exhibit of Maps Relating to Maryland and Chesapeake Bay.* Washington College, Chestertown, MD.

Mountford, A.R.
1971 *Staffordshire Salt-glazed Stoneware.* Praeger, New York.

Narroll, Raoul
1962 Floor area and settlement population. *American Antquity* 27:87-89.

Neiman, F.D.
1978 Domestic architecture of the Clifts Plantation Site: the social context of early Virgina building. *Northern Neck Historical Magazine*, 28:3096-3128.

1980a *The "Manner House" before Stratford (Discovering The Clifts Plantation).* Robert E. Lee memorial Association, Stratford VA.

1980b *Field Archaeology of The Clifts Plantation Site, Westmoreland County, VA.* Ms. on file Robert E. Lee Memorial Association, Inc. Stratford VA.

n.d. What happened to time in historical archaeology? Submitted to *American Antiquity*.

Newcomer M.H., R. Grace and R. Unger-Hamilton
1986 Evaluating microwear analysis with blind tests. *Journal of Archaeological Science* 13:203-218.

1988 Microwear methodology: a reply to Moss, Hurcombe and Bamforth. *Journal of Archaeological Science* 15(1):25-33).

Nishida, T.
1987 Local traditions and cultural transmission. In *Primate Societies*, edited by B.B. Smuts, D.L. Cheney, R.M. Seyfarth, R.W. Wrangham and T.S. Struhsaker, pp 462-474. University of Chicago Press, Chicago.

Noel Hume, Ivor
1972 *Guide to the Artifacts of Colonial America*. Knopf, New York.

1982 *Martin's Hundred*. Knopf, New York

O'Brien,P.
1982 European economic development: The contribution of the periphery. *Economic History Review* 35:1-18.

O'Connell, J.F.
1987 Alyawara site structure and its archaeological implications. *American Antiquity* 52:74-108.

Odell, G.H and F. Cowan
1987 Estimating tillage effects on artifact distributions. *American Antiquity* 52:457-484.

Outlaw, A.O.
1978 Governor's Land Archaeological District Excavations: the 1976 Season. Ms. on file Virginia Division of Historic Landmarks.

Parkington, John C.
1987 On carbon isotopes and dietary reconstruction. *Current Anthropology* 28(1):91-93).

Paynter, R.W.
1982 *Models of Spatial Inequality: Settlement Patterns in Historical Archaeology*. Academic Press, New York.

Phillips, P., J.A. Ford, and J.B. Griffin
1951 Archaeological Survey in the Lower Mississippi Alluvial Valley, 1940-1947. *Papers of the Peabody Museum* 25.

Platt, J.R.
1964 Strong inference. *Science* 146:347-352.

Plog, S.
1980 *Stylistic Variation in Prehistoric Ceramics*. Cambridge Univerity Press, New York.

Plotkin, H.C. and F.J. Olding Smee
1981 A multiple-level model of evolution and its implications for sociobiology. *The Behavioral and Brain Sciences* 4:225-268.

1982 Learning in the context of a hierarchy of knowledge gaining processes. In *Learning, Development and Culture*, edited by H.C. Plotkin, pp 433-471. John Wiley and Sons, London.

Pogue, D.J.
1988 Spatial analysis of the King's Reach Plantation Homelot, ca. 1690-1715. *Historical Archaeology* 22:40-56.

Popper, K.
1963 *The Poverty of Historicism*. Routledge and Kegan Paul, London.

Potts, R. and P. Shipman
1981 Cutmarks made by stone tools on bones from Olduvai Gorge. *Nature* 191:577-80.

Provine, W.
1971 *The Origins of Theoretical Population Genetics*. University of Chicago Press, Chicago.

Pulliam, H.R. and C. Dunford
1980 *Programmed to Learn, An Essay on the Evolution of Culture*. Columbia University Press, New York.

Quine, W.V.O.
1960 *Word and Object*. M.I.T. Press, Cambridge.

Richmond
5 *Richmond County Deeds, Book 5.* Ms. on file, Richmond County Courthouse.

Robinson, M.P.
1918 Viginia counties: those resulting from Virginia legislation. *Virginia State Library Bulletin* 9(1-3).

Rockman, D.D. and N.A. Rothschild
1984 City tavern, country tavern: and analysis of four colonial sites. *Historical Archaeology* 18(2):112-121.

Rogers, A.
1982 Data collection and information loss in the study of spatial pattern. *World Archaeology* 14(2):249-258.

1988 Does biology constrain culture? *American Anthropologist* 90:819-831.

Rosenburg, Alexander
1980 Obstacles to the nomological connection of reasons and actions. *Philosophy of Social Science* 10:79-91.

Roughgarden, J.
1979 *Theory of Population Genetics and Evolutionary Ecology: An Introduction.* Macmillan, New York.

Rouse I.B.
1939 Prehistory in Haiti: A Study in Method. *Yale University Publications in Anthropology* 21.

1967 Seriation in Archaeology. In *American Historical Anthropology: Essays in Honor of Leslie Spier*, edited by C.L. Riley and W.W. Taylor, pp. 153-195. Southern Illinois University Press, Carbondale.

Rubenstein, D.I.
1986 Ecology and sociality in horses and zebras. In *Ecological Aspects of Social Evolution*, edited by D.I. Rubenstein and R.W. Wrangham, pp. 282-302. Princeton University Press, Princeton.

Rutman, D.B. and A.H. Rutman
1984a *A Place in Time: Middlesex County, Virginia, 1650-1750.* W.W. Norton, New York.

1984b *A Place in Time: Explicatus.* W.W. Norton, New York

SAS Institute
1985a *SAS/GRAPH User's Guide, Version 5.* SAS Institute, Inc. Cary NC.

1985b The MATRIX Procedure: Language and Applications. *SAS Technical Report P-135,* SAS Institute, Inc. Cary NC.

1985c *SAS User's Guide: Statistics, Version 5.* SAS Institute, Inc. Cary NC.

Sabloff, J.A., L.R. Binford and P.A. McAnany
1987 Understanding the archaeological record. *Antiquity* 61:203-209.

Sahlins, M.
1976 *Culture and Practical Reason.* University of Chicago Press, Chicago.

Schofield, R.
1983 The impact of scarcity and plenty on population change in England, 1541-1871. *Journal of Interdisciplinary History* 14(2):265-291.

Schiffer, M.B.
1972 Archaeological context and systemic context. *American Antiquity* 37(2):156-165.

1976 *Behavioral Archeology.* Academic Press, New York.

1983 Toward the identification of formation processes *American Antiquity* 48(4):675-706.

1985 Review of *Working at Archaeology,* by L.R. Binford. *American Antiquity* 50(1):191-193.

1987 *Formation Processes of the Archaeological Record.* University of New Mexico Press, Albuquerque.

Schneider, D.M.
1976 Notes toward a theory of culture. In *Meaning in Anthropology,* edited by K. Basso and H.A. Selby, pp.197-220. University of New Mexico Press, Albuquerque.

Sealey, Judith C. and Nicholaas J. van der Merwe
1986 Isotope assesmenmt and the seasonality-mobility hypothesis in the Southwestern Cape of South Africa. *Current Anthropology* 27(2)135.

Sellars, Wilfrid
1963 Philosophy and the scientific image of man. In *Science, Perception and Reality,* edited by Wilfrid Sellars, pp.1-40. Routledge and Kegan Paul, New York.

Seyfarth, R.M. and D.L. Cheney
1984 Grooming, alliances, and reciprocal altruism in vervet monkeys. *Nature* 308:541-543.

Skibo, J.M., M.B. Schiffer and K.C. Reid
1989 Organic-tempered pottery: an experimental study. *American Antiquity* 54:122-146.

Skellam, J.G.
1950 Random dispersal in theoretical populations. *Biometrika* 30:196-218.

Smith, E.A.
1983 Anthropological applications of optimal foraging theory: a critical review. *Current Anthropology* 25:625-651.

1987 Optimization theory in anthropology: applications and critiques. *In The Latest on the Best, Essays on Evolution and Optimality,* edited by John Dupre, pp. 201-249. MIT Press, Cambridge.

Smith, J.T.
1970 The evolution of the English peasant house to the late seventeeth century: the evidence of buildings. *Journal of the British Archaeological Associction* 33:122-147.

Smith, P.
1980 The architectural personality of the British Isles. *Archaeologica Cambrensis* 129:1-36.

Smolek, M., D.J. Pogue, and W.E. Clark
1984 Historical archaeology in the 17th-century Chesapeake: a guide to the sources. *Jefferson Patterson Memorial Park and Museum, Occasional Paper, No. 1.* St. Leonard, MD.

Smuts, B.
1987 Sexual competition and mate choice. In *Primate Societies,* edited by B.B. Smuts, D.L. Cheney, R.M. Seyfarth, R.W. Wrangham and T.S. Struhsaker, pp 385-399. University of Chicago Press, Chicago.

Sober, E.
1980 Evolution, population thinking and essentialism. *Philosophy of Science* 47:350-383.

1984 *The Nature of Selection.* MIT Press, Cambridge.

South, S.
1977 *Method and Theory in Historical Archaeology.* Academic Press, New York.

Spier, L.
1917 An outline for a chronology of Zuni ruins. *American Museum of Natural History, Anthropological Papers* 18(3).

Stein, J.
1985 Interpreting sediments in cultural settings. In *Archaeological Sediments in Context*, edited by K.K. Stein and W.R. Farrand, pp.5-19. Center for the Study of Early Man, University of Maine, Orono.

1987 Deposits for archaeologists. *Advances in Archaeological Method and Theory* 11:337-395.

Steponaitis, V.C.
1983 *Ceramics, Chronology and Community Patterns: an Archaeological Study at Moundville.* Academic Press, New York.

Stone, G.W.
1974 St. John's: archaeological questions and answers. *Maryland Historical Magazine*. 69:146-168.

1982 *Society, Housing, and Architecture In Early Maryland: John Lewger's St. John's.* Ph.D. Dissertation, Department of American Civilization, University of Pennsylvania.

Sullivan, A.P.
1978 Inference and evidence in archaeology: a discussion of conceptual problems. *Advance in Archaeological Method and Theory* 1:183-222.

Symons, D.
1987 Darwin and human nature. *Behavioral and Brain Sciences* 10:89.

Taylor, W.W.
1949 A Study of Archaeology. *Memoirs of the American Anthropological Association* 69.

Templeton, A.
1982 Adaptation and the integration of evolutionary forces. In *Perspectives on Evolution,* edited by R. Milkman pp. 15-31. Sinauer Associates, Sunderland, MA.

Toobey, J. and I. DeVore
1987 The reconstruction of hominid behavioral evolution through strategic modelling. In *Evolution of Human Behavior: Primate Models,* edited by W.G. Kinzey. SUNY Press, Albany.

Trivers, R.
1985 *Social Evolution.* Benjamen/Cummings Publishing Co., Menlo Park.

Tukey, J.
1977 *Exploratory Data Analysis.* Addison Wesley, Reading MA.

U.S. Bureau of the Census
1975 *Historical Statistics of the United States, Colonial Times to 1970*, Part 2. U.S. Government Printing Office, Washington, D.C.

Upton, D.
1980 *Early Vernacular Architecture in Southeastern Virginia.* Ph.D. Dissertation, Department of American Civilization, Brown University.

van den Berghe, P.
1983 Human inbreeding avoidance: culture in nature. *Behavioral and Brain Sciences* 6:91-123.

van der Merwe, Nicholaas J.
1984 Carbon isotopes, photosythesis and archaeology. *American Scientist* 70:596-606.

van Valen, L.
1973 A new evolutionary law. *Evolutionary Theory* 1:1-30.

Virgina Land Patents
4 *Virginia Land Patents, Book 4*, Ms. on file Virginia State Library.

Vokes, H.
1957 Geography and Geology of Maryland. *Maryland Geolological Survey Bulletin 19*, Baltimore.

Vrba, E.S.
1983 Macroevolutionary trends: new perspectives on the roles of adaptation and incidental effect. *Science* 221:387-389.

Vrba, E.S. and N. Eldredge
1984 Individuals, hierarchies and processes: towards a more complete evolutionary theory. *Paleobiology* 10:146-171.

Vrba, E.S. and S.J. Gould
1986 The hierarchical expansion ofsorting an selection: sorting and selection cannot be equated. *Paleobiology* 12(2):217-228.

de Waal, F.B.M.
1987 Dynamics of social relationships. In *Primate Societies*, edited by B.B. Smuts, D.L. Cheney, R.M. Seyfarth, R.W. Wrangham and T.S. Struhsaker, pp 421-429. University of Chicago Press, Chicago.

Wallerstein, I.
1974 *The Modern World System: Capitalist Agriculture and the Origins of the European World Economy in the Sixteeth Century.* Academic Press, New York.

Wartenburg, D., S. Ferson and F.J. Rhölf
1987 Putting things in order: A critique of detrended correspondence analysis. *The American Naturalist* 129:434-448.

Washburn, W.
1972 *The Governor and the Rebel.* Norton, New York.

Watkins, C.M.
1960 North-Devon Pottery and its Export to Aamerica in the Seventeenth Century. *United States National Museum Bulletin 225.* Washington, D.C.

Watson, Patty Jo
1979 *Archaeological Ethnography in Western Iran.* Wenner Gren Foundation for Anthropological Research, New York.

Wenke, R.J.
1981 Explaining the evolution of cultural complexity: a review. *Advances in Archaeological Method and Theory* 4:79-127.

Westmoreland
2 *Deeds, Wills, etc. 1661-1662.* Ms. on file, Westmoreland County Couthouse, Montross, VA.

3 *Orders, 1662-69.* Ms. on file, Westmoreland County Couthouse, Montross, VA.

4 *Deeds, Patents, Wills, 1665-1677.* Ms. on file, Westmoreland County Couthouse, Montross, VA.

5 *Orders, 1678-1689.* Ms. on file, Westmoreland County Couthouse, Montross, VA.

7 *Orders, 1698-1705.* Ms. on file, Westmoreland County Couthouse, Montross, VA.

8 *Orders, 1705-1721.* Ms. on file, Westmoreland County Couthouse, Montross, VA

10 *Deeds and Wills, Book 1.* Ms. on file, Westmoreland County Couthouse, Montross, VA.

15 *Deeds and Wills, Book 6.* Ms. on file, Westmoreland County Couthouse, Montross, VA.

17 *Deeds and Wills, Book 8.* Ms. on file, Westmoreland County Couthouse, Montross, VA.

Westmoreland Inventories
1 *Inventories, Book 1.* Ms. on file, Westmoreland County Couthouse, Montross, VA.

Wetherill, C.
1984 "Boom and bust" in the Chesapeake economy. *Journal of Interdisciplinary History.* 15(2):185-210.

Whallon, R.
1984 Unconstrained clustering for analysis of spatial distributions in archaeology. In *Intrasite Spatial Analysis in Archaeology,* edited by H. Hietala, pp. 242-277. Cambridge University Press, Cambridge.

Williamson, M.H. and K.C. Brown
1986 The analysis and modelling of British invasions. *Philosophical Transactions of the Royal Society of London, Series B* 314:505-522.

Wilson, E.O.
1975 *Sociobiology: The New Synthesis.* Harvard University Press, Cambridge.

Wilson, E.O. and W.H. Bossert
1971 *A Primer of Popluation Biology.* Sinauer Associates, Sunderland MA.

Wimsatt, W.
1980 Reductionist research strategies and their biases in the units of selection controversy. In *Scientific Discovery: Case Studies,* edited by T. Nickles, pp.213-259. D. Reidel, Dordrecht.

Wissler, C.
1916 The application of statistical methods to the data on the Trenton Argillite Culture. *American Anthropologist* 18:190-197.

Wylie, Alison
1985 Putting Shakertown back together: Critical theory in archaeology. *Journal of Anthropological Archaeology* 4:133-147.

Wyrick, C.H.
1971 Stratford and the Lees. *Journal of the Society of Architectural Historians* 30(1).

Yellen, J.E.
1977 *Archaeological Approaches to the Present: Models for Reconstructing the Past.* Academic Press, New York.