

A DESIGN THEORY PERSPECTIVE ON VARIABILITY IN GRINDING STONES

by

Gayel A. Horsfall

B. A. Simon Fraser University 1979

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

in the Department

of

Archaeology

C Gayel A. Horsfall 1983

SIMON FRASER UNIVERSITY

March 1983

All rights reserved. This work may not be reproduced in whole or in part, by photocopy or other means, without permission of the author.

PARTIAL COPYRIGHT LICENSE

I hereby grant to Simon Fraser University the right to lend my thesis, project or extended essay (the title of which is shown below) to users of the Simon Fraser University Library, and to make partial or single copies only for such users or in response to a request from the library of any other university, or other educational institution, on its own behalf or for one of its users. I further agree that permission for multiple copying of this work for scholarly purposes may be granted by me or the Dean of Graduate Studies. It is understood that copying or publication of this work for financial gain shall not be allowed without my written permission.

Title of Thesis/Project/Extended Essay

A Design Theory Perspective on Variability

in Grinding Stones

Author:

(signature)

Gayel Ann Horsfall

(name)

30 March 83

(date)

APPROVAL

Name: Gayel A. Horsfall

Degree: Master of Arts

Title of Thesis: A DESIGN THEORY PERSPECTIVE ON VARIABILITY
IN GRINDING STONES

Examining Committee:

Chairperson: Richard Shutler, Jr.

Brian Hayden
Senior Supervisor

Jack Nance

Marilyn Gates
External Examiner
Department of Sociology and Anthropology
University of Simon Fraser

Date Approved: March 30, 1983

ABSTRACT

Grinding stones are often of considerable importance in the subsistence economy of traditional societies. However, they have received minimal analytical attention by archaeologists. Using ethnoarchaeological data from one Maya Highland village, the concepts of design analysis are used to determine the implications of variation in grinding stone material and morphology. Results are compared to ethnoarchaeological data from a second village, as well as to available data in the ethnographic, archaeological, historical and modern industrial literature.

Variation in grinding stone material exists in traditional societies and is related to variation in grinding function. The strength of the relationship appears to increase as the quantity and economic importance of the substance being processed increases.

Variation in grinding stone morphology reflects the interaction of stone material characteristics, technology, socioeconomic organization and function. Functional concerns focus primarily on increasingly efficient use of human energy, although morphological expression of this concern varies. Development of craft specialization and a market economy occur repeatedly as factors affecting grinding stone variation, and appear to be related in part to increased artifact demand.

ACKNOWLEDGMENTS

There are many people to whom I wish to express my appreciation for their encouragement, whether direct or indirect. In the broadest sense these people include Art Charlton, who many years ago opened the door of archaeology to me; and Brian Hayden, who more recently encouraged me to go through that door. In a more specific sense acknowledgment is due to my committee: Dr. Brian Hayden, Dr. Jack Nance; and Dr. Marilyn Gates, who consented to serve as external examiner. Thanks are also due to Dr. Erle Nelson, who has always given freely of his time, thoughts and encouragement.

I would also like to take this opportunity to express my thanks to my fellow graduate students, from whom I have learned much both archaeological and otherwise.

Considerable recognition is due my family: to my husband Bob, who has endured and continues to provide intellectual and emotional encouragement; and to my son Andy, who has provided encouragement and who manages quite well on his own.

Finally, and in some ways most importantly, special appreciation goes to Ramon Ramos Rosario and his family, and to the people of San Mateo, particularly Xun and Petul Xantex. The kindness with which they welcomed us into their homes and the tolerance with which they greeted our naivete went well beyond that required by simple human courtesy.

TABLE OF CONTENTS

Approval	ii
Abstract	iii
Acknowledgments	iv
Table of Contents	v
List of Tables	viii
List of Figures	ix
I. INTRODUCTION	1
Theory	2
Methodology	6
Data	11
San Mateo	11
Aguacatenango	20
II. CONSTRAINTS ON THE SELECTION OF MATERIAL FOR GRINDING	
STONES	23
Functional Constraints Suggested by San Mateo Data	24
Technological Constraints Suggested by San Mateo Data	29
Social Constraints Suggested by San Mateo Data	31
Comparisons of San Mateo Results With Data From Other	
Sources	32
Functional Constraints	33
Technological Constraints	36
Social Constraints	37
Modern Materials Data	39
Discussion of Constraints on Selection of Material for	
Grinding Stones	42

III. CONSTRAINTS ON THE MORPHOLOGY OF GRINDING STONES	51
Functional Constraints Suggested by San Mateo Data	54
Material and Technological Constraints Suggested by San Mateo Data	63
Social Constraints Suggested by San Mateo Data	64
Comparisons of San Mateo Results With Data From Other Sources	64
Functional Constraints	64
Technological Constraints	72
Social Constraints	73
Discussion of Constraints on the Morphology of Grinding Stones	76
IV. CONSTRAINTS ON THE NUMBER AND LOCATION OF GRINDING STONES	80
Functional Constraints Suggested by San Mateo Data	81
Social Constraints Suggested by San Mateo Data	83
Archaeological Visibility of the Systemic Context Suggested by San Mateo Data	88
Comparisons of San Mateo Results With Data From Other Sources	89
Discussion of Constraints on the Location and Number of Grinding Stones	96
V. MODERN INFLUENCES ON THE TREATMENT AND USE OF TRADITIONAL GRINDING STONES	98
Functional Constraints Suggested by San Mateo Data	99
Technological Constraints Suggested by San Mateo Data	101

Social Constraints Suggested by San Mateo Data	103
Comparisons of San Mateo Results With Data From Other Sources	106
Discussion of Modern Influences on the Treatment and Use of Traditional Grinding Stones	113
VI. CONCLUSIONS	116
Physical Attributes	116
Adaptive Behavior	121
Future Considerations	125
References Cited	127

LIST OF TABLES

Table

1	Grinding Stone Function and Material: San Mateo	17
2	Grinding Stone Function and Form: San Mateo	19
3	Use-Life Estimates and Reported Ages of Basalt Metates and Manos: San Mateo and Aguacatenango	27
4	Time Spent Grinding Maize: San Mateo	57
5	Comparison of Grinding Surface Area for Metates and Special Purpose Grinding Stones: San Mateo	61
6	Grinding Stone Measurements from Several Regional Centers	69
7	Comparison of Sizes of Tripodal Metates: San Mateo and Aguacatenango	76
8	Household Family Type and Number of Metates: San Mateo and Aguacatenango	84
9	Herb Preparation Artifacts and Associations: San Mateo	87
10	Positive and Negative Attributes of Alternate Maize Grinding Technologies	102
11	Corngrinder Ownership and Technological Attributes: San Mateo	104
12	Comparison of Economic and Social Characteristics: San Mateo and Aguacatenango	109

LIST OF FIGURES

Figure

- 1 Tripodal Maize Grinding Metate with Proximal Leg Placed
on Post: San Mateo 13
- 2 Prehispanic Plano-Convex Grinding Stone with Cylindrical
Mano: San Mateo 15
- 3 Unmodified Boulder Clothes Washing Stone with Use-Wear:
San Mateo 16
- 4 Prehispanic Mano of Conglomerate and Cylindrical Mano:
San Mateo 53
- 5 Woman Grinding Coffee on Tripodal Metate Placed on Floor
with Containers to Catch Spillage: San Mateo 56
- 6 Comparison of Grinding Stone Surface Area by Function:
San Mateo 62
- 7 Prehispanic Plano-Convex Grinding Stone with Proximal
End Placed on Post: Aguacatenango 67

I. INTRODUCTION

Writing in 1931 with respect to the Yucatan peninsula Gustav Stromsvik noted that maize grinding stones, or metates, had failed to receive their due share of attention in spite of the fact that they are and were the most important item of household equipment (Stromsvik 1931:143). Two years later, Kathleen Bartlett made a similar observation for the American Southwest (Bartlett 1933:3). After fifty years their comments could be repeated with little modification. Variation in shape and material of grinding stones in space and time can provide information concerning culture chronology and culture contact (MacNeish et al 1967:v), as well as short-range trade in non-exotic goods (Weaver 1972:158; Scholes & Roys 1968:319). Even for these purposes, however, there are discrepancies and major omissions in the reporting and analysis of grinding stones (Coe 1965:599; Longyear 1952:105; Hammond 1975:344; Cook 1973:1485-1486). No consideration has ever been given to the possibility that variation in material, morphology, or distribution within a site may relate to functional variation, or have implications concerning the nature of socioeconomic organization at both the community and household levels. The following thesis, using data collected during recent ethnoarchaeological research in the Maya Highlands, will argue that grinding stones offer considerable potential for understanding both prehistoric lifeways and cultural process,

and deserve the attention Stromsvik and Bartlett have called for.

Theory

One of the more useful theoretical frameworks for integrating information obtainable from grinding stones (or other artifacts) is design analysis, or design theory. Design theory deals with the process of creating and making artifacts, and was first suggested as applicable for archaeological interpretation by Kleindienst (1975:383). She argued that understanding material culture involves understanding how artifacts are made and use, and ultimately how they "...allow actors within cultural behavioral systems to adapt in their environments" (Kleindienst 1975:383). The importance of the design process derives from the fact that it involves the differential selection of raw materials and their modification in order to achieve a desired end product within a particular context. In other words, it is one of the processes which articulates the material and non-material aspects of culture. Unfortunately, as Kleindienst points out, present theory concerning the articulation is largely implicit, intuitive, ethnocentric, and devoid of any reference to the design process.

Design theory has been developing for the past three decades in the realms of architecture, engineering and industry (Jones 1970:3). However the main thrust has been in describing new methodological techniques, particularly for increasing creativity and formalizing decision-making (Jones 1970; Starr

1963; Hill 1970). Consideration of the relationship of the material product of the design process to the broader cultural context, when it occurs, is apt to stress the importance of product innovation in order to maintain corporate sales and growth (Hill 1970:1-2). More generally consideration for the product of the design process with the cultural context is subsumed under the very specific statement of the design problem. In other words, most design theorists are concerned with how to improve product creation rather than with understanding the way in which the design process articulates the material and non-material aspects of culture. The broader theoretical perspective is provided by two authors, Pye and Alexander (Pye 1964, 1968; Alexander 1974). Because Alexander and Pye are concerned with the process of design, rather than specific methods, it is their work which provides the basis for the theoretical model used here.

The fundamental assumption of design theory is that artifacts are made for a reason--not simply to serve a function, but to solve an activity or adaptive "problem". The particular problem may be related to economic, technological, social or ideological behavior patterns, or some combination of these (Alexander 1970:15ff).

The operational assumption of design theory is that a number of constraints operate on the production and final form of artifacts. Constraints may be considered in terms of material, technology, function, and social factors. These

constraints operate interactively, and may come into conflict. For example, the "best" material for a particular function may not be available, or the technological capability for handling it may be unknown or dependent on a particular form of social support system, or there may be ideological objections to using it. The final artifact therefore represents a satisfactory solution to a total set of particular constraints, or a specific context.

Specifying the constraints involved in solving a problem defines the context of the adaptive problem being solved. Changing the nature of one or more constraint in effect changes the nature of the problem. One of the critical points made in design theory is that a satisfactory solution to one set of constraints is not the "best" solution to a particular problem. Both the interactive nature of a given set of constraints and the potential for redefining a problem by changing one or more constraint means there will never be a "best" solution to any problem, but many possible satisfactory solutions (Alexander 1970:17). Furthermore, the interactive and changeable nature of constraints provides the potential--perhaps even the impetus--for change over time.

For purposes of archaeological interpretation, determining the relative importance of various constraints in producing the artifact should provide insight into the nature of the adaptive problem being solved. Analyzing the economics of time, energy, and risk involved in the procurement and use of materials and

manufacture of artifacts can provide one means of specifying many of the constraints. Particular attention should be paid to explaining apparent diseconomies, since these diseconomies are usually balanced by increased economies with respect to some other constraint or constraints. In this way the constraints which were of greatest importance to the people producing the artifacts can be identified and evaluated in terms of their adaptive implications.

There are two possible sources of criticism concerning use of this very generalized model of design theory. On the one hand, much of what is stated explicitly in design theory has been accepted implicitly and/or intuitively in archaeology for some time. However, human mental capacities are such that intuitive analysis is limited to relatively simple problems. Furthermore, intuitive analysis is not easily accessible to criticism. Making explicit that which has been implicit will improve the results of even the simplest analysis as well as increasing the complexity of the analyses which may reasonably be undertaken (Alexander 1974:5-9). On the other hand, there may be concern for the lack of a rigorous experimental-statistical approach commonly found in the industrial and engineering contexts. While such an approach is ultimately desirable, the present state of knowledge (or more accurately, lack of knowledge) is such that it is inappropriate. What is needed at the present time is the development of empirical models which can then be subjected to more rigorous

testing.

Methodology

Design theory, through the notion of multiple interactive constraints in the production process, provides a general framework for relating material items back to the cultural context. Archaeologists, however, must deal with specifics: the specifics of material and form of items and their variation within time and space, and how these relate back to specific cultural contexts. Unfortunately, because of the general lack of research dealing with grinding stones, there is very little information in either the ethnographic or the archaeological literature. Where information exists it is sparse, fragmentary, and frequently devoid of concern for the nature and possible implications of variation.

Need for basic data of this sort was the basis for initiating the Coxoh Ethno-archaeology Project. Since the data used here were provided by the Project, a brief description of relevant aspects of its goals and methods are provided.

The Coxoh Ethno-archaeology Project was initiated to assist in solving problems of archaeological interpretation arising from excavation of Colonial Coxoh sites in eastern Chiapas, Mexico by the New World Archaeological Foundation. In particular, a data base concerning the functions and social contexts of a wide variety of material items was desired. Because the Coxoh, a Mayan people, are extinct, field work was done among closely related groups still living in the

surrounding area. This included (but was not limited to) formal data collection in two relatively traditional Maya villages during February and March 1979. These were the Chuj-speaking village of San Mateo Ixtatan, in the Department of Huehuetenango, Guatemala, and the Tzeltal-speaking village of Aguacatenango, in the state of Chiapas, Mexico. In each village a number of households was sampled. Because the ethnographic field work was dependent on the cooperation and goodwill of the people with whom work was being done, use of statistical sampling procedures was necessarily precluded. However, every effort was made to include as broad a range of the social and economic spectrum as possible. This included the range of annual income and land ownership, craft and service specializations, and religious and political office holders. It was felt that this goal was achieved.

For each household sampled two types of data were collected, in accordance with the goals of the Project. The first type of data, concerning material items, was obtained through an inventory of material items in all structures and the associated compound for each household. The function of artifacts was determined by direct questioning and by observation. The materials from which artifacts were made was determined by observation. For the most part informants were amazingly cooperative in allowing access to all items in their possession. Rarely was access denied to any part of a household. In those few households where limitations were

imposed, they were not for areas likely to contain grinding stones.

The second type of data collected from each household in a systematic fashion concerned the socioeconomic context. This was obtained by interviewing an adult member of the household. In order to insure comparability and consistency of data between households the interviews were structured by a series of questionnaires on social, demographic, economic factors, as well as architectural features and artifact use and use-life. Interviewing was done by two members of the research team working together, while two other members undertook the material survey. All members of the research teams made an effort to insure that inventory and interview data was consistent within and between households.

In addition to systematic data collection, observations and informal interviews were used in San Mateo to obtain users' explanations for variation in form and material for a number of items, including grinding stones. Data of this nature was not collected from every household, since it was necessary for variation to be present in order to raise questions about it. When variation in form or material occurred in a household, every effort was made to avoid the use of leading questions. Open ended questions were best handled when the objects in question were at hand. Another reason data of this sort was not collected from every household was the need to avoid a proliferation of questions. Questions were not repeated after a

series of reasonably consistent responses was obtained.

Another source of data was obtained through unstructured interviews with and observation of individuals practicing traditional crafts. These included several visits to Ramon Ramos Rosario, a present-day manufacturer of manos and metates in the village of Malacatancito, a short distance from the city of Huehuetenango.

Selection and interpretations of data concerning grinding stones provided by the Coxoh Ethno-archaeology Project was guided by concern to maintain comparability with an archaeological situation. Thus, information concerning variation in material, morphology (including size), and spatial distribution was treated as the primary data base. Each of these variables will be dealt with separately, and potential reasons for the observed variation will be sought in the sources of constraint in the design process. Potential sources of constraint include function, technology and social organization (including ideology). Where variation in physical properties appears to be associated with variation in a source of constraint, explanation will be sought in economics of time, energy and potential risk. As well, it is expected that apparent diseconomies will occur as a result of conflict between constraints. Particular attention will be paid to these apparent diseconomies as possible indicators of the nature of the adaptive problem or problems being solved.

In addition to the effort to interpret variation in physical properties of grinding stones, consideration will be given to the impact of modern industrial society on their presence and use in the current ethnographic context. This, again, is done in order to increase the applicability of results to archaeological contexts where modern industrial influences are not present.

In the effort to interpret variation in each of the primary variables--material, morphology, and distribution--inferential statistics will be used where sufficient data exist. This will be primarily the data obtained through the material inventory and the structured interviews. Since selection of households from which this data was obtained was not based on statistical procedures, inferences derived from statistical tests must, strictly speaking, be applied to the sample only, not the population from which it was drawn. However, this limitation can to some extent be compensated. First, as already mentioned, the household samples are felt to be reasonably representative of their respective villages. Second, use will be made of the comparative method, as discussed below.

Interpretation of the data obtained through observation and informal interviews a more discursive and inferential treatment is necessary. Due to the lack of previous research and the subsequent exploratory nature of the present research, this discursive approach necessarily constitutes a significant portion of the interpretation.

When research is largely exploratory in nature, there is a problem with providing some check on the conclusions and interpretations. Ultimately this is done through further research and testing. In the meantime, however, the fact that comparable data was obtained in two villages by the Coxoh Ethno-archaeology Project provides the potential for a comparative approach. Thus, interpretation, as discussed above, will make use of the data provided obtained from San Mateo, where the most information on grinding stones was collected. Interpretations based on the San Mateo material will be checked against the data from Aguacatenango, as well as relevant information concerning grinding stones in the ethnographic, archaeological, historic and materials literature. As already noted, information in the literature is sparse and fragmentary. However, much of it comes from cultural contexts different from that of San Mateo, while Aguacatenango does not.

Data

San Mateo

The village of San Mateo lies high in the Cuchumatane Mountains, about 75 km from Huehuetenango. Relatively isolated, the village has only been accessible by road for the past 20 years and retains traditional lifeways in many respects, particularly in terms of material culture. The present-day village is built directly on top of a Late Classic site, with a Post-Classic site a short walk away on the outskirts of the

village. At least two other prehispanic sites are reported to lie within a few hours walking distance.

The primary economic base for San Mateo is the traditional Mesoamerican subsistence maize horticulture. This is supplemented in a variety of ways, including part-time craft and service specializations, and wage labor on low-land plantations. The products of many part-time specialists, such as potters, carpenters, and hunters, are used within the village. In other words, the community is largely self-sufficient. Outside sources of income include the wage labor already mentioned, sale of salt from the local mines (although this is of declining importance), and some cash crops.

There are over 600 households in San Mateo, no more than a dozen of which are Ladino (behaviorally associated with the politically dominant Latin society). Fifty-one households were sampled for the Project. These included two Ladino households, the poorest household in the village (annual income of US\$15), the richest (annual income of (US\$3377), and representatives of all craft and service specializations.

All but five of the households surveyed had one or more grinding stones, or metates, which were used to grind maize, the mainstay of the diet. All maize grinding metates were of basalt, and all were the three-legged or tripodal form (Fig. 1). While maize grinding was the primary function of these metates, other, occasional, uses were reported. Such uses included grinding roasted beans, achotes (a coloring "spice"), chiles,



Figure 1. Tripodal Maize Grinding Metate with Proximal Leg Placed On Post: San Mateo

salt, and the calcite crystals used as temper in pottery making. In some households a separate basalt metate was used to grind coffee and cacao. This constituted a specialized use, or sometimes reuse, of the basalt metates.

In addition to the basalt metates several households had other grinding stones, made of quartzite, limestone, conglomerate, and a greenstone schist. These were used for washing clothes, mashing herbs, grinding coffee, salt, and calcite. Some, recovered from local archaeological sites, were of a plano-convex form (Fig. 2). The remainder were unshaped, other than by use (Fig. 3). Clothes washing stones, while not generally considered grinding stones, are included in this analysis in part because the wear pattern they develop can be very similar to that found on other grinding stones.

A total of 120 grinding stones was recorded in San Mateo during the material inventory. In terms of function, 56% of these were currently in use as maize grinding metates. All of these were of basalt (Table 1). The second most common use, accounting for 12.5% of the sample, was coffee grinding. The majority of these were also of vesicular basalt. Clothes washing accounted for six percent of the "grinding" stones found in households or compounds. Although nearly all of these were of quartzite or conglomerate, this is probably a biased sample in terms of material. The majority of the stones used in public areas outside the compounds for scrubbing clothes were of the local hard limestone. These were generally used near the

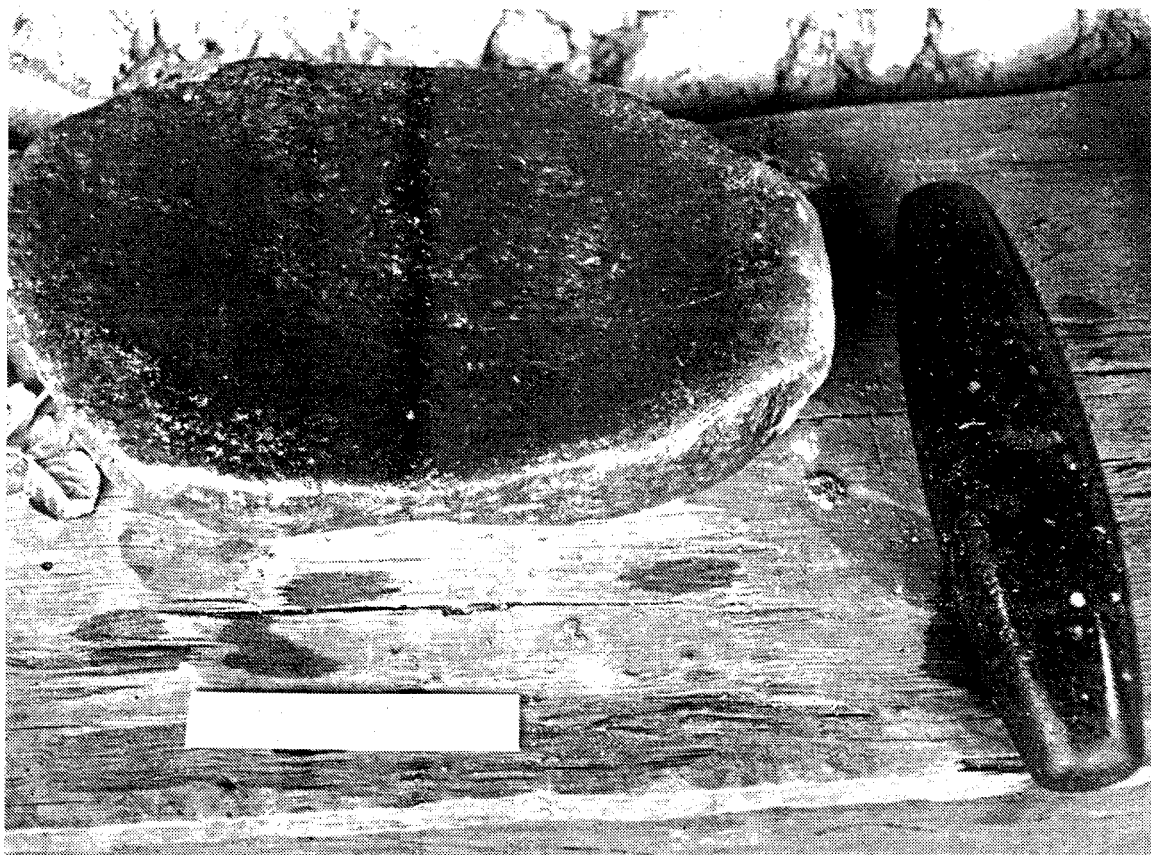


Figure 2. Prehispanic Plano-Convex Grinding Stone with Cylindrical Mano: San Mateo. (Scale = 15 cm)



Figure 3. Unmodified Boulder Clothes washing Stone with
Use-Wear: San Mateo. (Scale = 15 cm)

Table 1. Grinding Stone Function and Material: San Mateo

Primary Function	Material								Total Function
	VB*	Qz*	Cg*	Ls*	Sd*	GS*	Ss*	Nr*	
Maize Grinding	67								67
Coffee Grinding	13		2						15
Clothes Washing		4	2	1					7
Herb Mashing		3		1	1	1			6
Calcite Grinding		1		1				2	4
Salt Grinding	2						1		3
Toys	3								3
In Storage	15								15
Total Material	100	8	4	3	1	1	1	2	120

*VB=Vesicular Basalt; Qz=Quartzite; Cg=Conglomerate;
 Ls=Limestone; Sd=Sedimentary; GS=Greenstone Schist;
 Ss=Sandstone; Nr=Not recorded

streams and springs where they were found, with the result that they were not represented in the household inventories. Stones used for herb mashing accounted for another five percent of the sample. Many households also made use of washing stones for mashing herbs. Other households used a plain wood board, the top of the maize grinding table, or a special wooden trough

mortar for mashing herbs. Three percent of the recorded grinding stones were used specifically to grind calcite for pottery making. Two-and-one-half percent were used for grinding salt, and another two-and-one-half percent were used as toys. With the exception of one slab of sandstone used to grind salt, the salt and toy grinding stones were all quite small. The remaining 12.5% of the grinding stones were of an unspecified function, being in storage. Since all were of vesicular basalt, they presumably were intended either for maize and/or for coffee grinding. It should be noted that in terms of material and shape, the modern basalt metates, irrespective of function, constituted 82.5% of the sample (Tables 1 & 2).

San Mateo retains traditional lifeways in many respects, particularly in terms of material culture. However, increased contact with the modern economic world since the building of the road has had some impact. Food preparation patterns, for example, have been partially modified by the introduction of motor-driven corn grinding mills. The first of these appeared fifteen years ago, and at the time of the survey there were four in operation. They were patronized extensively by the women of San Mateo. In addition to the motor-driven mills, 18 surveyed households had hand-cranked metal corngrinders. Metal corngrinders first appeared in San Mateo about twenty years ago, five years before the appearance of the first motor-driven mill.

Modern technology has had some impact on other grinding functions, as well, specifically clothes washing and herb

Table 2. Grinding Stone Function and Form: San Mateo

Primary Function	Un-Modified	Form		Not Recorded	Total Function
		Plano-Convex	Tripodal		
Maize Grinding			67		67
Coffee Grinding		3	12		15
Clothes Washing	6			1	7
Herb Mashing	4	2			6
Calcite Grinding	2			2	4
Salt Grinding		1	2		3
Toys			3		3
In Storage			15		15
Total Form	12	6	99	3	120

preparation. The impact on clothes washing behavior was probably minimal. Five surveyed households had scrubboards of a sort commonly used in Western Industrial society two or three generations ago. None of these were ever seen in use, however. In addition, a few households (only one of which was surveyed) had concrete water holding tanks, with a flat surfaced scrubbing basin on one side. The impact of modern technology on the practice of herb preparation and use was probably greater.

Commercial medicines were available in the market and were used, although to what extent is not known. There were also two sources of modern professional medical care in San Mateo. One source was a program sponsored by the Guatemalan government whereby young doctors were required to serve an internship in native villages, providing free medical care to the villagers. Although extensively used, the availability of this service could be somewhat erratic. There was also a small hospital run by the Catholic church, which charged a minimal fee for medicine and services.

Aguacatenango

The village of Aguacatenango, in the southern Mexican state of Chiapas, is about 40 km from San Cristobal de las Casas. Like San Mateo, the primary economic base for Aguacatenango is traditional Mesoamerican subsistence maize horticulture, supplemented by part-time craft specialization, wage labor, and cash garden farming. Aguacatenango differs from San Mateo primarily in having a higher dependence on wage-labor as a source of external income. There are no salt mines in Aguacatenango, however there is a nearby lake from which some fish are obtained. There are approximately 250 households in Aguacatenango, none of which are Ladino. Fifty households were included in the Aguacatenango sample.

The total number of grinding stones recorded in Aguacatenango was 131. All sampled households had one or more modern tripodal metates of andesite, made in Chamula, Chiapas.

These accounted for 82% of the sample and were used primarily for grinding maize. The remaining 23 recorded stones (18%) were used specifically for other purposes. These included grinding calcite (6%) and pigments (1.5%) for pottery making, reuse as architectural material (paving and stepping stones, e.g.) (6%), grinding coffee (1.5%), and mashing herbs (1%). Only one grinding stone (1%) was recorded as not in use. Of these special grinding stones at least three were made of limestone. Morphologically they included plano-convex (Fig. 2) forms, unmodified forms (Fig. 3), as well as the modern tripodal form (Fig. 1). Those that were not reused modern metates were primarily retrieved from nearby archaeological sites. Four households also had wooden tobacco mortars. There were no washing stones, as clothes were washed in wooden tubs, bought in regional markets.

In Aguacatenango all but three households had metal corngrinders. There was one motor-driven mill in Aguacatenango, although it was not extensively patronized. The Mexican government also provides fairly reliable medical services to native villages.

It is clear even from this initial, superficial presentation of the data that variation in grinding functions does exist and to some extent covaries with material and form. This functional variation is seldom noted in the literature. Of the few instances where it is mentioned, as in McBryde's (1947:47) brief comment that separate grinding stones were used

for separate functions in Southwestern Guatemala, mention is almost never made of material variation.

II. CONSTRAINTS ON THE SELECTION OF MATERIAL FOR GRINDING STONES

Of the grinding stone attributes that will be treated as dependent variables--material, morphology, and distribution--material is one of the more easily and reliably determined archaeologically. Material is therefore the first dependent variable to be considered from a design theory perspective. Many of the materials used for grinding stones are readily available in the area around San Mateo. Limestone, in particular, is abundant in many sizes and shapes. With the exception of the vesicular basalt, the other stones are probably also obtained locally. Vesicular basalt, however, is imported. The time and energy invested in importing a non-local material represents an apparent diseconomy in material selection. In spite of this, the imported material accounts for 83% of the total sample, and appears to be closely associated with maize and coffee grinding. Other "grinding" functions are almost exclusively associated with local materials. There are thus two basic questions to be addressed in the analysis of material. First, what constraints influence the choice of material. Second, what benefits are gained by the importation of vesicular basalt that compensate for the costs of importation, and what are the adaptive implications. As stated earlier, these questions will be approached through a consideration of the constraints, or independent variables, of function, technology,

and social factors.

Functional Constraints Suggested by San Mateo Data

Informants were asked on several occasions what material attributes they looked for in stones for specific grinding functions. Responses varied, depending on the intended use of the stone. For washing stones and herb mashing stones a number of informants stated that the material attribute of most importance was, in their words, hardness. One informant stated that stones which gave off grit were undesirable. While this was the only mention of material texture, it was observed that most of the washing and herb mashing stones were relatively smooth. The attributes of texture and grit may also be reflected in informants descriptions of the stones as hard, since the materials used for clothes washing and herb mashing stones often were not hard in the scientific sense. Essentially, if the material was "hard" enough, it would not give off grit. The distinction between stone and wood for herb mashing seemed to be a matter of personal preference. Those who used stones claimed that they mashed the herbs more finely, and/or kept the odor from permeating the house when used outdoors. Those who used wood argued that it was cleaner, for "Who knows what has been on the stones outdoors!".

The fineness of the ground substance was also noted as important by those informants who used quartzite and conglomerate for grinding coffee. These materials were said to give a finer grind. They also did not allow the finely ground

and highly valued coffee to be "lost" in the holes, as vesicular basalt did. Recovery of the ground material may be of greater concern for more expensive substances, such as coffee, since it was repeatedly stated that loss of the ground maize in the vesicles of the basalt was minimal and not a problem. The vesicular basalt metates used for grinding coffee were not resharpened (repecked), and developed a distinctive polish. Whether the polish was an organic residue "polish" or a real polishing of the stone, it definitely tended to obscure the vesicles. This may also have increased the fineness of the grind by altering the texture of the stone, a possibility that might be tested in the future.

It has been reported that vesicular basalt does not need to be repecked or resharpened (Aschmann 1949:685), a characteristic that presumably would increase its desirability as a grinding stone. However, the practice of resharpening or repecking vesicular basalt metates was consistently reported in San Mateo. Usually resharpening was done with an old, broken machete blade, axe blade, or hoe blade, although one informant used a quartz pebble, and one used a prehispanic stone celt. When all maize grinding was done on a metate, it was said to need resharpening about three times a year or more. (One informant stated that metates were resharpened as often as 15 times a year, but this is probably an exaggeration.) With the introduction of the motor-driven mill, reported resharpening decreased slightly to about twice a year. Perhaps the most critical point to be made

with respect to resharpening, however, is the importance of another attribute so basic that it tends to be overlooked by both users and analysts--sharpness in the stone texture. A sharp--or rough--texture would obviously be a desirable stone attribute for real grinding. Equally obvious is that a sharp or rough texture would be an undesirable stone attribute for some of the other "grinding" functions, such as clothes washing and herb mashing.

Another characteristic of basalt that may be related to its desirability for maize grinding is that it does not give off much grit when being used. Perhaps because all maize grinding was done on basalt metates, the only mention of grit by an informant was as an undesirable characteristic of sandstone for scrubbing clothes. Grit was mentioned by Ramon Ramos, however, who contrasted vesicular basalt with the andesite of Nahuala, Guatemala. He claimed that only vesicular basalt did not leave a gritty residue.

Use-life is often an important material attribute, and use-life estimates were obtained for vesicular basalt metates in San Mateo. These ranged from 10 to 100 years, with a median of 35 years. Reports of actual ages of metates still in use were also obtained. The median reported age was 20 years, with a range from one to 100 years (Table 3). Although informant estimates of this sort are often subject to some inaccuracy, the two sets of estimates are sufficiently similar to suggest that expected use-life estimates are probably fairly reliable.

Table 3. Use-Life Estimates* and Reported Ages of Basalt Metates and Manos: San Mateo and Aguacatenango

No. of Years	Use-Life Estimates of Metates: San Mateo	No. of Households Reporting		Use-Life Estimates of Manos: San Mateo	Reported Ages of Manos: San Mateo
		Reported Ages of Metates: San Mateo	Reported Ages of Metates: Aguacatenango		
1 - 2	0	1	1	0	2
3	0	2	1	1	2
4	0	1	2	0	1
5	0	2	3	0	3
6	0	0	4	5	0
7	0	1	0	0	1
8	0	2	1	1	2
9	0	0	0	0	0
10	3	5	3	2	6
15	4	1	2	4	2
20	3	4	7	11	3
25	3	0	1	1	1
30	2	4	2	2	5
35	4	2	1	1	2
40	2	4	1	0	1
45	1	1	1	0	0
50	2	1	6	0	1
55	1	0	0	1	0
60	3	0	0	2	0
65	0	1	0	0	1
70	0	0	0	0	0
75	2	0	0	0	0
80	1	0	0	0	0
85	0	0	0	0	0
90	0	0	0	0	0
95	0	0	0	0	0
100	<u>6</u>	<u>1</u>	<u>2</u>	<u>1</u>	<u>0</u>
	37	33	38	32	33
Med.	35.0	20.0	20.0	20.0	10.0

*Prior to the use of modern grinding technology.

Furthermore, from a user-oriented perspective the use-life estimates suggest that a metate could reasonably be expected to last about the adult lifetime of a user.

During the course of discussing the use-life of metate stones with users, it was discovered that there were two grades of basalt which were distinguished because of differences in expected use-life. The preferred grade of basalt, called "black" stone (a dark, low-vesicular basalt), was considered superior because it was harder and therefore lasted longer. The inferior grade of basalt, referred to as "white" stone (containing more small vesicles, with light crystal coatings) was cheaper, but was also softer and did not last as long. The differences in use-life characteristics of different stones was corroborated by Ramon Ramos. According to him, use-life was highly correlated with stone hardness, with softer materials lasting about 15 years. He estimated that harder materials could last anywhere from 30 to 100 years, depending on the care with which they were used. The distinction between grades of basalt may account for the rather extreme range of use-life estimates, reflecting differing expectations for different stones. Furthermore, it supports the importance of use-life as a material attribute, since this was the basis for evaluating the basalt. One informant stated that there was no difference in the grinding ability of the two types of stone.

In summary, the functional constraints on material selection for grinding stones include whether the substance to be processed on the stone will be actually ground, as opposed to mashed or rubbed; the undesirability of grit as a by-product of use; and the desired fineness of the ground product. In

addition, full recovery of the ground product may sometimes be important, particularly for precious products such as coffee; and an extended use-life seems to be important for the economically important maize grinding metates. The actual stone characteristics mentioned by informants as being related to these constraints included hardness, color, and, indirectly, texture. Of these the definition and perception of color and hardness are highly culture bound, as in informant descriptions of limestone as hard, and the local distinction between "black" and "white" vesicular basalt. Stone texture, along with other attributes such as resistance to abrasion, appear to be more closely related to functional constraints and will be considered more fully below.

Technological Constraints Suggested by San Mateo Data

Obtaining information from residents of San Mateo concerning technological constraints on material selection was not possible, since no one there manufactured grinding stones. Where locally available materials were used, they were largely unmodified. However, Ramon Ramos provided considerable information concerning the working of vesicular basalt, which in many instances may be extended to other materials.

Ramon Ramos stated that the primary stone characteristic he looked for was resistance to breakage (in his words, "heart"). It was also necessary for the material being worked to be "softer" than the tools used to work it. He said that the highly vesicular ("white") material was the easiest to work, and

was less likely to break. Ramon Ramos' preference for the "white" stone presents a direct conflict between functional and technological constraints, since this material was considered inferior by users. Ramon Ramos also differed from users in that he did not categorize materials as simply good or bad, but seemed to regard them more in terms of a continuum. He had a tendency to regard each sample of stone as unique, based on the relative ease with which it could be worked and the potential risks that might be encountered in working it.

Another possible consideration in material selection is the trauma inflicted on the worker's hands in manufacturing a grinding stone, and the need to develop tough hands. While this might not ordinarily be considered a technological constraint, it is probably just as important as the acquisition of technological knowledge and skill. Specifically, without the development of appropriately toughened hands an individual would probably have to treat the process of shaping as part-time, piece meal work. Under these conditions there would probably be an even greater preference for softer, easier to work, materials.

In summary, the most important aspect of technological constraints on grinding stone material selection is that they appear to be antithetical to functional constraints. Technological concern for material resistance to breakage, workability of the stone, and reduction of trauma to the hands all leads to a preference for a softer material. Functionally,

however, the harder materials are considered better.

Social Constraints Suggested by San Mateo Data

At first glance social factors would appear to have little influence on the choice of material for grinding stones, especially since much of the variation in material can be explained by variation in function. The effect of craft specialization and a market economy, or the social organization of production and distribution of modified materials, does have some impact, however. The most obvious effect is that the regional market economy increases the range of materials available, so that residents of San Mateo are not totally restricted to what is locally available. At the same time, craft specialization and subsequent marketing may impose some more subtle limitations on material availability, as suggested by two San Mateo informants. One informant, who was very thrift conscious, complained that metates made of the cheaper material were difficult to obtain. The other informant, on the other hand, stated that metates made of the cheaper material were easier to obtain than the better, more expensive ones. There is a possibility that some seasonal variation exists in the availability of materials, as Ramon Ramos' production and sales are to some extent tied to the occurrence of local festivals and the migration of workers to the lowlands. Unfortunately, no information is available on the relative quantities of different grades of basalt or seasonal variation in their availability in the Huehuetenango market where the majority of San Mateo

residents currently buy their metates. The comments of the two informants do suggest that both minor and major variation in material availability and use might be affected by the socioeconomic organization of production and distribution. Before such a possibility can be fully explored, however, there needs to be greater recognition of the occurrence and importance of material variation.

Another possible social influence on the choice of material is in the use of greenstone schist for one herb mashing stone. The stone occurred side by side with a clothes washing stone of quartzite. Since washing stones and herb mashing stones were often used interchangeably, the presence of two different stones suggests some redundancy, or a diseconomy of time and energy in procurement. The ideological and ritual importance of green-colored stone throughout prehispanic Mesoamerica is well known. Within this traditional context there may also have been a weak association of the color green with the general concept of health (Roys 1965:xvi). Although the specific use of the greenstone schist for herb mashing in San Mateo may simply have been an individual aberration, it may also have reflected that particular household's adherence to a traditional world view, including belief in the symbolic efficacy of green-colored stone.

Comparisons of San Mateo Results With Data From Other Sources

The majority of constraints on the selection of grinding stone materials suggested by the San Mateo data were related to

the intended function of the stone. They included whether or not the substance to be processed was to be actually ground, the desired fineness of grind, resharpening need, extent of use-life, presence of grit, and recovery of ground material. Ethnographic, historic, and archaeological accounts tend to support the relevance of these constraints.

Functional Constraints

An excellent archaeological example of the variation of grinding stone function and material comes from the Papaguera, in the American Southwest. Vesicular basalt was imported to saguaro collection camps, where metates were made and used to grind the seeds of the saguaro fruit, which have a high oil content. In contrast, sandstone and quartzite metates were found in organ pipe cactus collection camps. These were used to grind the organ cactus seeds, which were first dried and parched (Goodyear 1975:84-88, 104, 185-187). In other words, although cactus seeds were being ground in both instances, the nature and consistency of the seeds was radically different in the two cases and apparently justified the use of different grinding stone materials.

The importance of grinding, as opposed to rubbing or mashing may be noted in historic millstones which were often grooved, partly to insure that the grain was cut rather than crushed (Moritz 1958:37). Similarly, early Canadian millstones used for grinding were often imported from France in part because the French stones were naturally sharp in texture (Leung

1981:38).

Fineness of grind as a concern is apparent in the American Southwest and in historic milling technology. In order to obtain meal of sufficient fineness the Hopi used three grades or textures of sandstone for their grinding slabs (Bartlett 1933:4). Stone texture, or grain size, is one way of controlling the fineness of the ground product. Another way, more commonly used in Europe and the historic New World, is to sift the ground product (Storck and Teague 1952:53; Leung 1981:44-47).

With respect to resharpening, Russell (1908:108) notes that the Pima resharpen their grinding stones, made from a coarse grained local material, with an axe or a stone of similar shape. Unfortunately, he does not mention frequency of resharpening. Bartlett (1933:4) notes that the sandstone metates of the Hopi are resharpened every five days with a hammerstone. This is not strictly comparable with San Mateo, since maize in the Southwest is not precooked (Nelson 1981:110) and three different grades of sandstone are used to complete a single grinding (Bartlett 1933:4). It does suggest one possible extreme in resharpening frequency, however. Baja California is at the other extreme, where it was reported that vesicular basalt metates were not resharpened at all. Here however, their primary use was apparently for grinding coffee, not maize (Aschmann 1949:683). As noted for San Mateo, when a separate basalt metate is used for grinding coffee, it is not repecked or resharpened. In

present day Ocozocoautla, Chiapas, metates are apparently resharpened only once every year or two (Clark 1980:56). This may be influenced by the use of modern metal corngrinders to do the first, rough, grinding of the maize, with the result that there is less wear on the metate. Historic millstones were also resharpened, the frequency varying from once every few days to as often as every day, depending in part on the type and extent of grinding being done (Runnels 1981a:245; Leung 1981:98). In modern commercial contexts, the problem of resharpening is avoided by using--or more often manufacturing--a stone where the bonding strength is such that grains tend to break free at about the time they become dull (Brady 1971:378).

An overt concern for the use-life of grinding stones as a factor in material selection is most explicit in references to historic milling stones (Leung 1981:38; Runnels 1981a:62). It is also mentioned as one of the criteria influencing material selection for the maize grinding metates made in Chamula, Chiapas, and in Oaxaca (Pozas 1959:100; Cook 1981:V-12). Actual use-life estimates of grinding stones are rare, and do not take into account material variation. Cook gives an average of fifteen years for granitic metates in Oaxaca (Cook 1970:785), while Aschmann gives estimates of fifteen and twenty years for vesicular basalt metates in Baja California (Aschmann 1949:685,686). Use-life estimates of andesite metates in Aguacatenango are not available, although the reported ages of metates still in use ranged from one to 100 years, with a median

of 20 years (Table 3). This is the same as for the vesicular basalt metates of San Mateo. Bartlett does not give use-life estimates for the Hopi sandstone grinding slabs, although she mentions that obtaining new sandstone material is an annual women's ritual (Bartlett 1933:14), suggesting that the use-life may be relatively short, perhaps only a few years.

Undesirability of grit in the ground product has been mentioned in connection with both Roman and historic commercial millstones (Storck and Teague 1952:vi; Runnels 1981a:143; Leung 1981:38). It has also been noted elsewhere in the Maya area (Hayden in press:24). For the remaining functional constraint, recovery of ground material, there are no references in the literature, suggesting, as did the San Mateo informants, that this may only rarely be a significant concern.

Technological Constraints

Turning to the technological constraints on grinding stone material selection, it will be recalled that the "softer"--and less durable--material was easier to work, and less likely to break. The metate makers of Oaxaca also prefer working softer material, which they can judge by the lesser feeling of shock in response to striking it (Cook 1973:1500). This stone is less desirable from the user's perspective because it is less durable and needs more frequent resharpener. Apparently, however, not all buyers are aware of the more durable stone (Cook 1981:V-12, 13). Pozas' description of material selection by Chamula metate makers mentions the two constraints of function and technology.

There, potential material sources are tested to determine how easily they break, and also their ability to withstand the wear of grinding (Pozas 1959:100). Unfortunately, he does not mention whether the two attributes conflict, and if so, which is given greater importance. Runnels (1981a:62) also mentions both workability and durability as important constraints on selecting stone materials for Greek milling stones.

Social Constraints

The effect of social organization in the form of craft production and regional marketing on grinding stone material selection can be seen throughout much of Mesoamerica. The maize grinding metates used in Aguacatenango are manufactured of andesite in Chamula, which supplies the metates used throughout the Tzotzil area (Laughlin 1969:162--although Laughlin refers to them as basalt). In Baja California, the vesicular basalt metates of one craft specialist may be found up to 250 miles away (Aschmann 1949:685). In southwestern Guatemala there are only two active metate production centers: Malacatancito, where basalt metates are made, and Nahaula, where metates are made of andesite (McBryde 1947:61). In Wisdom's discussion of Eastern Guatemala, metates were manufactured only in Jilotepeque, Jalapa. These were made of granite and widely distributed (Wisdom 1940:24). Where craft specialization occurs, the materials used appear to be basalt, andesite, or granite, depending on regional availability. In contrast, sandstone is used among the Hopi, where grinding stone production is

apparently not a craft specialization. According to Bartlett (1933:14), the women are aware of and prefer vesicular basalt, however sandstone sources are closer to the village and material procurement has been incorporated into a women's ritual. Among the Pima, as well, metates are made by owners from a local coarse grained material. Prehistorically, however, the Hohokam imported vesicular basalt metates into the same area (Russell 1908:109). The effect of social organization on material selection may also be seen in the Old World. In Bronze Age Greece there was a shift from local materials (sandstone) to imported materials (andesite) which occurred concurrently with a shift to specialized production and regional rather than local distribution (Runnels 1981b:3).

References to green colored stone used to mash medicinal herbs do not occur in the ethnographic literature. This may indicate that the San Mateo example was unique, or--more likely--may be a result of the paucity of ethnographic interest in special use grinding stones. Green metates, although rare, are found archaeologically, usually in Late Classic contexts (Coe 1959:34; Hammond 1975:344; Kidder 1947:33; Thompson 1939:173). Unfortunately, contextual information other than chronology is usually lacking. One exception is the greenstone metate found at Seibal. It occurred in association with a fragment from an alabaster vessel at the edge of a small mound that was part of a household complex (Tourtellot 1970:412). Tourtellot suggested that this may have been used for grinding

pigments, although no traces remained. Only one other "private" mound was found during excavation of the residential area for Seibal, and this was a burial mound.

Modern Materials Data

Comparative data concerning constraints on material selection is available from modern industrial society as well as the ethnographic and historic sources referred to above. Within the context of modern technology, functional constraints on stones used for grinding or abrading include the desired fineness of grinding, durability (use-life), resistance to dulling, efficiency (productivity), hardness of the substance being ground, and uniformity of grinding and wear (Brady 1971:4-6, 378, 515). Fortunately the relationship between these constraints and a number of material attributes is fairly well known. The attributes generally considered important include mineral grain size, grain hardness and fracture characteristics, strength of grain bonding, and grain spacing or structure.

Grain size is related to the desired degree of fineness of the ground product, with the smallest grain sizes used for polishing (Brady 1971:6). Grain size may also be related to durability, with finer-grained stones tending to be more durable (Murphy 1957:93, 340-341). Grain hardness is also matched to the substance being processed, with the harder grained stones used for harder substances. For modern abrasive materials the distinction between hard and soft appears to fall at about 6 on the Mohs scale, with the softer abrasives used primarily for

polishing. The stones considered desirable for milling cereals are generally harder (Brady 1971:4-6, 515).

Fracture characteristics of the stone grain are mentioned primarily in the context of resistance to attrition prior to dulling (Brady 1971:6), although presumably they would affect sharpness as well. Grain bonding is also important for durability of the grinding stone. The bonding should be strong enough to withstand the pressures to which the stone is subjected during use and to resist excessive attrition. At the same time it should not be too strong, as the retention of dulled grains results in the dulling or glazing of the stone. The problems of glazing are apparently particularly critical for sandstone (Brady 1971:6, 378).

Grain structure affects the amount of material that can be processed in a given time, with a porous or open cellular structure giving freer cutting. An open cellular structure seems to be characteristic of the most desirable stones for milling cereals (Brady 1971:6, 515). It is also of particular importance for the efficient grinding of relatively soft or "rubbery" substances, such as cereals with a high moisture content (Leung 1981:40).

Finally, for modern industrial users of grinding stones uniformity of grain size and hardness are considered extremely desirable. Uniformity of stone material insures both more even grinding and more even wear of the grinding stone. In fact, rather than being made of natural stones most grinding and

abrasive stones today are manufactured in order to insure uniformity of grain size and hardness (Brady 1971:4, 377, 378, 513).

The ability to evaluate the workability of stone materials is as important to modern sculptors as it is to makers of grinding stones. Among the stone properties sculptors consider are the presence of flaws, hardness, texture, and brittleness (the tendency of the material to shatter) (Rich 1947:268, 214, 269). Of these properties the freedom from flaws, such as cracks, veins, or stratification is considered most important. These flaws are said to result in "dead" stone, which gives off a dull sound when struck (Rich 1947:269). Hardness of the stone is determined primarily by the bonding of the grain or crystal structure. As the strength of the bonding increases, the stone becomes harder and more difficult to work. Stones of igneous origin are generally among the hardest materials, although the hardness of granite may vary considerably depending on the quartz content, crystal size and structure. Some sandstones, with a highly siliceous cementing matrix, may also be quite hard (Rich 1947:268, 270, 214, 221).

Texture of the stone material is its superficial appearance. Texture is determined by the grain or crystal size and arrangement, including the compactness or porosity of the grain structure (Rich 1947:268). Uniformity in texture is more important to sculptors than the actual grain or crystal size, as uniformity reduces risk to the carver, whose skill depends in

part on the development of a consistent, uniform approach in handling stone material. Sandstones are often difficult to carve because of irregularities in texture and hardness. More porous materials may sometimes be easier to work, but are generally not used by sculptors as they do not take a good polish. Among sculptors uniformity of texture is considered more critical than relative softness (Rich 1947:214, 218-222, 225-226, 269).

Brittleness of stone materials is a complex property, resulting in part from microflaws in the material. These flaws may be inherent in the stone, or may result from weathering. In general, smaller grained, more compact materials are less apt to be brittle. Granites are particularly susceptible to brittle failure, particularly those with a high mica content (Rosenthal & Asimow 1971:124-127; Murphy 1957:340-342; Rich 1947:241).

Discussion of Constraints on Selection of Material for Grinding Stones

This section on grinding stone materials was begun with two questions, what constraints influence the choice of material for grinding stones, and what benefits compensated for the costs of importing vesicular basalt. While all constraints appear to have some influence on the choice of material, the importance of function appears to be the strongest. It cannot be repeated too often that variation in the grinding function does exist. The substances being "ground" may vary in hardness and in moisture content. They may vary in whether they will be ground, rubbed,

mashed, crushed, or polished, and how finely. As well, the volume, or quantity of a substance to be processed can vary, as can the frequency of processing. Variation in the grinding function will be reflected to some extent in the choice of stone material, particularly its texture and hardness. As the volume of processing increases, the influence of the grinding function on choice of stone material will also increase.

The influence of technological constraints on grinding stone material selection appears to be considerably less than that of functional constraints. However technological constraints do exist: materials vary in the ease with which they can be worked and in their susceptibility to failure. The effect of technological constraints seems, however, either to be the introduction of minor variation in material selection (as in the preference of metate makers for the "softer" igneous stones), or to be a reflection of social constraints (as in the extensive use of igneous materials by craft specialists as opposed to the use of available sedimentary or metamorphic materials by non-specialists).

The effect of social constraints on grinding stone material selection, like the effect of technological constraints, appears to be relatively minor and perhaps indirect. It may sometimes reflect some sort of identification with a socially limited belief system, as in the choice of greenstone for an herb mashing stone. It is more likely, however, that the effect of social constraints on material selection reflects the social

resolution of conflicts in other constraints, such as the conflict between functional and technological constraints. This resolution, in turn, reflects the nature of the adaptive problem or problems being solved.

Explaining the use of vesicular basalt was the second question posed at the beginning of this section on material selection. In particular there was the question of what benefits would compensate for the costs of importation. At least three benefits seem to be associated with the use of vesicular basalt. These benefits are, first greater grinding efficiency in processing the relatively soft and moist pre-cooked maize; second, increased efficiency in processing large quantities of maize irrespective of its moisture content; and third, increased dependability of the grinding stone as a result of its longer use-life and reduced resharping needs. The fact that these benefits are of sufficient importance to justify the expense of importing stone reflects the importance of maize in the local diet. As maize or other grains increased in importance in the subsistence economy more would be processed, on a more regular basis. This would result in an increased amount of time spent grinding, increased use-wear on the stone, and increased stone procurement requirements. All these factors would increase the desirability of a more efficient and more durable material, such as vesicular basalt. However, this alone does not seem to be sufficient to result in the importation of vesicular basalt in all situations, such as

among the Hopi in the American Southwest. Addition of the third factor, precooking maize so that it is soft and moist, may be even more critical. Similarly, processing of a relatively soft, moist or oily substance, the olive, may have been a critical factor in increased use of andesite in Bronze Age Greece (Runnels 1981b:3-4, 6).

The stone properties associated with these benefits include the vesicular texture, or porous structure, and the material hardness. The porous structure increases the amount of material that can be ground in a given time, is resistant to polishing or dulling, and increases the ease of grinding soft, moist, precooked maize. The hardness of the stone and its resistance to dulling would both increase its use-life as a grinding stone. This same hardness, however, is technologically undesirable, resulting in a conflict of constraints. That there will be conflicts in constraints is a prediction made by design theory. As further predicted by design theory the resolution of such conflicts will depend on the cultural context and the nature of the adaptive problem being solved. The increased demand based on functional benefits may be a necessary condition for the importation of igneous materials. The increased technological difficulties of working igneous stone may be eased by the development of craft specialization. Thus, the development of craft specialization may, in this instance, represent a socioeconomic resolution of conflict between technological and functional constraints in a context where the functional

constraints represent a major adaptive problem.

Another situation where material choice which may indicate response to an adaptive problem is the preference for a finely ground product. A finely ground meal may be important when it will be cooked by baking rather than boiling, as this allows a quicker, more even cooking. A baked product is both more portable and has greater storage potential (Moritz 1958:145, 152), factors which are likely to be important when the product is the mainstay of the diet. Quickness of cooking may also be important in an area where fuel is limited or difficult to obtain. Even where the ground product is to be boiled or steeped (as coffee or an herbal tea), a more finely ground or mashed product will cook more quickly, and with more flavor. The opposite situation, where fineness of the grind may be undesirable, is suggested by Colson (1979:25) in her discussion of adaptive strategies in Africa. She states that the grinding stone is used rather than the wooden mortar in times of famine because the grinding stone does not remove the bran from the meal and thus provides a coarser but bulkier meal. Unfortunately, the situation with respect to mortars and grinding stones is considerably more complex than she implies. Wood mortars are or have been used in Africa, Asia, and probably pre-industrial Europe to dehusk grain prior to grinding it. Wood is used for dehusking mortars in order to minimize breakage of the grain before it is ground, making it easier to separate the bran and the grain (Moritz 1958:xxvi, 25, 27; Kraybill

1977:489, 492-3). Thus mortars and grinding stones serve very different functions and are generally not interchangeable. In many instances, as is almost certainly the case in Colson's example, they are both present and both used, at least in times of plenty (Moritz 1958:21-24; Goodyear 1975:165ff).

Colson's point, however, concerning the distinction between fine and coarse meal and its adaptive implications is well-made, and can, in fact, be extended. Where fineness of grind can be demonstrated to be a deliberate choice it appears to imply a condition of plenty of one sort or another, whether the plenty of an adequate subsistence base (as in Colson's example, and the example of baking), or the plenty associated with high social status in a hierarchical society. The later condition prevailed in Roman (and much more recent) times, when fine-grained white bread denoted higher status (Moritz 1958:xx). In the Maya area the maize for atole, with its ceremonial use and associations, must also be finely ground.

The relative importance of artifact use-life as a constraint in material selection may vary with both functional and socioeconomic context. The effect of functional context in the importance of use-life may be seen in San Mateo, in the difference between special purpose grinding stones and maize grinding metates. The special purpose grinding stones are used on an occasional basis to process substances of minor importance to the subsistence economy. Both because of their limited use and their limited economic importance, use-life is not an

important consideration for these stones. This, in turn, allows the procurement economy of local materials which would provide a relatively short use-life under conditions of extensive use. The maize grinding metate, on the other hand, is used intensively and extensively to process the major item of subsistence. Dependability of the stone, the assurance that it will be available and ready for use as needed, is critical. Extending the use-life of the stone is a major means of increasing that dependability. It will be recalled that the more highly valued "black" vesicular basalt was preferred because of its extended use-life, not because of its better grinding ability.

The effect of socioeconomic context on the relative importance of use-life may be seen in a comparison of San Mateo with modern industrial society, which suggests that the importance of functional dependability, or use-life, even for an economically critical artifact, may vary with the extent to which a society remains self-sufficient. While San Mateo does participate in a regional market system, it remains relatively self-dependent economically. By contrast our own society is highly interdependent, and the planned obsolescence of most household artifacts is considered essential for the maintenance of the economy. Often "modernness" is considered a more important attribute than an extended use-life for these artifacts. At the same time it is interesting to note that dependability of tools is a major concern of modern-day

homesteaders who are attempting to return to a more traditional, self-reliant life style.

Throughout the discussion of materials use has been made of generally accepted geologically defined categories such as basalt, quartzite, and sandstone. However, one of the important conclusions to be drawn from both informant comments and modern technological data is that choice of material for both user and manufacturer is based on material attributes or properties that have a more direct bearing on function and manufacture. These attributes, for grinding stones, include grain size and arrangement or structure, grain bonding and hardness, brittle strength, and freedom from flaws. Grain size and arrangement in combination result in material texture. Although all attributes have some bearing on the suitability of a material for use as a grinding stone, texture seems to be the most critical. Texture is related to the degree of fineness of grind of the ground product and its efficient processing both in terms of volume and moisture content, resistance to dulling and durability of the stone, the ease with which the stone may be worked, and its use-wear characteristics. Encouragingly, from an archaeological perspective, variation in texture is often visually perceptible, and an initial assessment may often be easily made.

This section on constraints on material selection for grinding stones can be concluded with a number of summary statements. It would seem that material selection is guided primarily by functional constraints, such as the nature of the

substance to be processed, the amount to be processed and the subsequent desired efficiency of processing, desired fineness of the ground product, and durability of the stone. In order to meet these constraints attention is paid to those material properties of particular relevance to the intended function, such as texture and hardness. The relative strength of individual constraints may vary, and there are likely to be conflicts between constraints. The resolution of conflict is apt to depend on the importance of the specific grinding process in the economy and the nature of the adaptive problem being solved, as well as in the alteration of the relative importance of one or more of the conflicting constraints in conjunction with socioeconomic change such as the development of craft specialization.

III. CONSTRAINTS ON THE MORPHOLOGY OF GRINDING STONES

Morphology is another grinding stone attribute often available archaeologically and is therefore the next dependent variable to be considered from a design theory perspective.

In San Mateo the simplest grinding stones were for the most part unmodified (Fig. 3). These constituted 12% of the sample, and were used primarily for washing clothes and mashing herbs (Table 2). Their selection for use was influenced in part by their natural shape, particularly the presence of a relatively flat surface. The prehispanic grinding stones, which constituted 5% of the sample, were plano-convex in shape (Fig. 2). In the present situation these were most commonly used for grinding coffee. Given the lack of data concerning variation in grinding stone function now and in the past their original use is unknown. The modern vesicular basalt grinding stones, or metates, accounting for 82% of the sample, were the only grinding stones which had been modified in the modern context. They were tripodal (Fig. 1), with two feet at the distal end and a slightly longer foot at the proximal end. The grinding surface was rectangular, flat, and slightly sloping due to the differential height of the feet. There was no rim. The handstone, or mano, used with the maize grinding metate was a long, cylindrical stone, tapering slightly towards the ends, and longer than the width of the metate. In theory the metate and its mano constituted a set, since they were made to fit

together. In reality, this was not always the situation, although manos were always of basalt and always longer than the width of the metate. Where manos were used with grinding stones other than the tripodal metates no effort was made to match grinding stone and mano in terms of material (Fig. 2). These manos tended to be whatever was readily available, including modern manos, fragments of modern manos, prehispanic manos, and river cobbles. They also tended to be shorter in length than the width of the grinding stone (Fig. 4).

The intentional modification of raw materials to form artifacts involves an expenditure of time and energy. Presumably, the more complex or detailed the shape, the greater the time/energy expenditure. Where the raw material undergoes little or no modification, consideration is usually given to the natural form of available materials as part of the selection process. While this constitutes a technological constraint of sorts, it is a relatively minor constraint. In San Mateo when locally available materials were used, they received little or no modification. In terms of the energy, time, and risk involved in selection and production these and the archaeological grinding stones are economical in both form and material. In contrast, the imported tripodal maize grinding metates are complex in form and represent a significant procurement and technological diseconomy when compared with simpler forms. The following analysis of form will therefore focus on two questions. First, what constraints influence the



Figure 4. Prehispanic Mano of Conglomerate (foreground) and Cylindrical Mano (background): San Mateo. (Scale = 15 cm)

form of grinding stones? Second, what specific constraints can account for the tripodal metate form found throughout Mesoamerica and only in Mesoamerica? As before, the independent variables or constraints to be considered will be function, technology, and social factors.

Functional Constraints Suggested by San Mateo Data

Observations of metates in the context of use suggest a number of functional constraints on grinding stone morphology. In San Mateo maize grinding metates were placed on a special grinding table which allowed the woman to stand while grinding. The natural slope of the grinding surface was sometimes increased by placing the slightly longer proximal leg on a post (Fig. 1). The slope of the grinding surface of metates in use ranged from four to 40 degrees with modes at 9-10 and 15-16 degrees ($n=35$). Women generally claimed that this slope made grinding easier. Water was used in grinding maize and controlling this water was a major problem. Excess water ran off the metate onto the grinding table and from there to the dirt floor. A wooden trough or broken, but useable, large ceramic vessel was generally placed along one side of the grinding table to catch maize grinding water. In addition, many households had constructed small drainage channels from the area around the grinding table to the exterior of the house. Even so, the floor surface around the grinding table was usually rather soft and muddy. Often, a stone or wood block had been placed next to the grinding table, allowing the woman to avoid

standing in the mud. In addition, the block allowed the woman to stand at a height sufficient to reach the far end of the metate comfortably. It was at the distal end of the metate that the greatest force was applied in the grinding motion. Perhaps because the maize was ground moist, there seemed to be little difficulty in keeping it on the metate while grinding.

Use of the tripodal metates for grinding coffee seemed to follow two patterns. A number of women placed the metate on a small table and used it in much the same manner as described above, except that coffee was ground dry. Because of this it had a tendency to spill over the sides of the metate. When this happened it was easily scooped up from the table surface and put back on the grinding stone or into a container. In the second pattern of use, the woman placed the metate on the floor, kneeling to grind. One woman observed grinding coffee in this fashion had placed a number of small dishes around and slightly under the edges of the metate to catch any spillage (Fig. 5).

The above examples suggest two sources of functional constraint on metate morphology. One is a concern for increased human energy efficiency, as reflected in increased ease of grinding from placing the grinding surface at an angle. The importance of improving the energy efficiency of maize grinding metates can be understood when the amount of time spent grinding prior to the advent of European alternatives was probably three hours per day or more (Table 4). Where maize was not precooked prior to grinding, the time requirements were undoubtedly

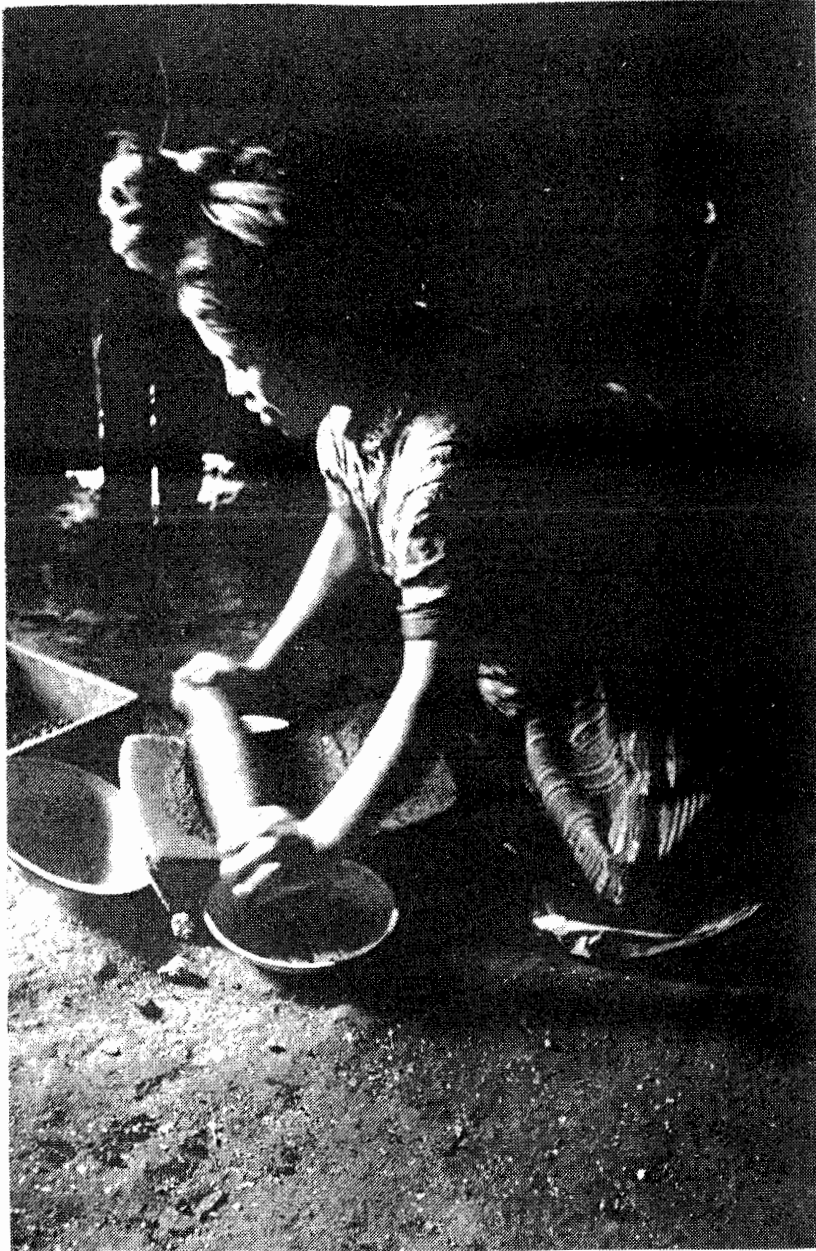


Figure 5. Woman Grinding Coffee on Tripodal Metate Placed on Floor with Containers to Catch Spillage: San Mateo

Table 4. Time Spent Grinding Maize: San Mateo

Reported Time To Grind Maize (In Hours/Day)	Using Metate Only: No. of Households Reporting	Using Metate and Motor-Driven Mill: No. of Households Reporting
0.00	0	1
0.25	0	1
0.50	0	1
1.00	0	2
2.00	1	0
3.00	3	0
4.00	1	0
5.00	0	0
6.00	<u>1</u>	<u>0</u>
	6	5

significantly greater. The second constraint on grinding stone form suggested by the San Mateo examples is a need to control the material being ground and any potentially messy or undesirable by-products, such as water.

It has been suggested that the slope of the grinding surface allows the woman doing the grinding to "put her back" into the grinding motion, increasing the weight on the mano and therefore on the grain (Wisdom 1940:88-89; Moritz 1958:29). However, grinding involves cutting or shearing, not crushing, and extra weight does not improve the efficiency of grinding (White 1962:108). The distinction between grinding and crushing is particularly applicable to maize and coffee, which are primarily ground rather than crushed. Thus, the benefits of "putting one's back" into the grinding motion is not likely to be in terms of the actual grinding. It is more likely that it is the change in body motion itself that is important.

According to human factors engineers, for a task that is both repetitive and time consuming, fatigue will be considerably reduced if motion is distributed about the body rather than concentrated in one part. For motions using the arm this means including the shoulder in the arm movement (Damon et al 1966:294). Thus, "putting one's back" into the grinding motion would be a more efficient use of human energy because it would be less tiring.

Placing the surface of a grinding stone at a slope would provide a physiological advantage for the person doing the grinding. It would also provide some mechanical advantage as well. This can perhaps best be visualized in terms of energy or force vectors. Assuming for the moment a level grinding surface, the person doing the grinding must apply force downward, to achieve contact between the upper and lower stones. In addition, force must be applied in a forward motion, moving the upper handstone along the lower stone. The two forces are perpendicular to each other, and will counteract each other, resulting in a minimally efficient ratio between energy expended and results. By placing the grinding surface on a slope--at an intermediate angle between the two required directions of force--the same force used to increase contact between upper and lower stones will also move the upper stone across the lower stone. Thus, more of the energy expended by the person doing the grinding can be utilized. Furthermore, if the angle of the forward thrust is slightly greater than the slope of the

grinding surface, minimal force will be applied at the beginning of the stroke, and maximum force at the end of the stroke. Both effects would be desirable, the first to insure that the grain is ground (sheared) rather than crushed, the second to act as a break to the forward motion. Here again, the use of the entire body as a brake would be less tiring than a specialized motion of a limited set of muscles.

The second constraint on grinding stone morphology suggested by the San Mateo observations was a need to control the substance being ground and any by-products of the grinding process. The legs on the tripodal metate may tend to facilitate this control in a number of ways. In the case of maize grinding, the metate is raised above the surface of the table where excess water accumulates. In the case of coffee grinding (and probably other dry substances), the legs allow the metate to be placed on a raised surface where spillage may be easily collected. Alternately, the legs allow the placement of containers under the edges of the grinding surface in order to catch spillage. At the same time, it is obvious that the problems of controlling spillage have not been fully resolved, only perhaps mitigated.

In addition to the constraints of energy efficiency and control of the ground product, another possible source of constraint on grinding stone morphology was suggested by Ramon Ramos. He stated that he made and sold many small metates for special uses, including the grinding of herbs, spices, and

cheese. These tended to be smaller than normal, though not miniature (Hayden:pers.comm.). Using the San Mateo data, the grinding surface areas for stones of different functions were compared. Although sample sizes are small, the mean size of the surface area for special purpose grinding stones other than those used for washing clothes was significantly smaller than for maize grinding metates. In contrast, the mean surface area of stones used for washing clothes was significantly larger than for maize grinding metates (Table 5). Unfortunately, although there is a statistically significant difference in the mean size by function of the three classes of grinding stones, there is also considerable overlap (Fig. 6). This is probably due in part to the fact that six of the eight coffee grinding stones were reused maize grinding metates.

One possible explanation for the relationship between grinding stone function and size may be the concern for energy efficiency. Specifically, the size of the working surface of a grinding stone may reflect the quantity of the substance being processed and the frequency of processing. A greater quantity could be processed in a given time on a large grinding surface than on a small one. The more frequently the substance was processed the more important this efficiency would be. The smaller size of the special purpose grinding stones may reflect not only their occasional use, often for smaller quantities, but also greater ease of storage between uses. The exception is the clothes washing stones, whose generally larger size would

Table 5. Comparison of Grinding Surface Area for Metates and Special Purpose Grinding Stones: San Mateo

Function	Mean Surface Area (in cm.sq.)	Student's <u>t</u> *a
Maize Grinding	1140.68 (<u>n</u> =52; <u>s</u> =188.14) (range=690-1645)	
Special Purpose Other Than Clothes Washing*b	744.56 (<u>n</u> =16; <u>s</u> =345.83) (range=82.5-1344)	4.386 (<u>p</u> <.05)
Clothes Washing	1650.00 (<u>n</u> =5; <u>s</u> =351.78) (range=1350-2250)	3.237 (<u>p</u> <.05)

*a: In all instances, a one-tailed test was used.

*b: Functions include coffee grinding (n=8), salt grinding (n=3), herb mashing (n=2), toys (n=2), and calcite grinding (n=1).

accomodate the greater bulk of clothing, and which remain in place outside the house or compcund when not in use.

Based on the San Mateo sample there appear to be two functional constraints on grinding stone morphology, the efficient use of human energy and control of the substance being ground, along with any by-products. Of these, concern for human energy efficiency seems by far the stronger constraint. It is expressed most explicitly in the slope of the grinding surface of the maize grinding metates, a slope which is built into the metate by the differing heights of the front and back legs. A concern for energy efficiency may also be reflectd in the variation in size of the grinding surface of stones for

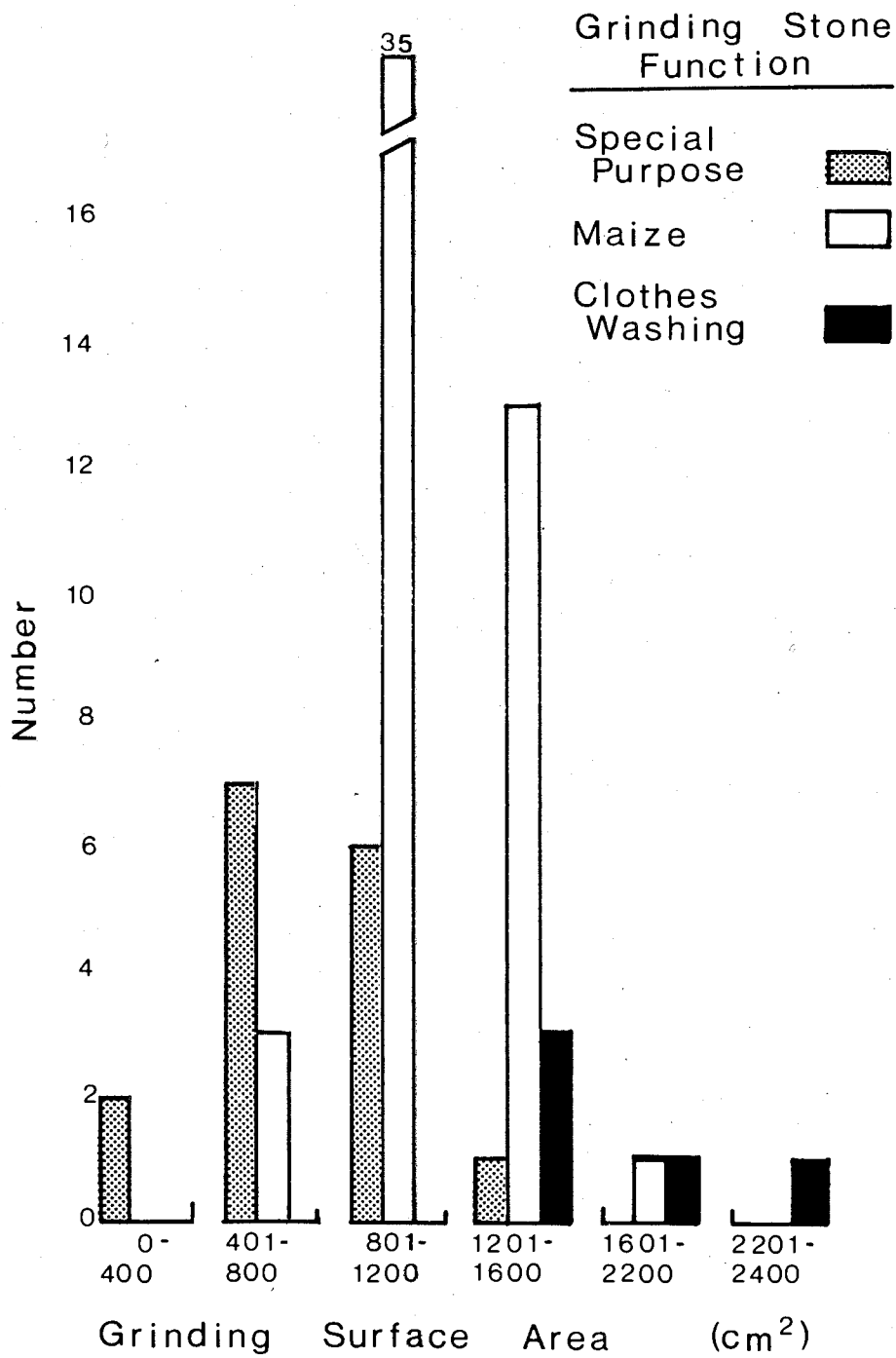


Figure 6. Comparison of Grinding Stone Surface Area by Function: San Mateo

different uses. Control of the product being ground seems a less compelling constraint on grinding stone morphology, inasmuch as there is still an obvious problem in this respect. However the problem seems to be partially mitigated by the presence of legs on the tripodal metates.

Material and Technological Constraints Suggested by San Mateo Data

As discussed in the section on material, it was not possible to obtain data concerning the technological constraints on form from residents of San Mateo, since no one there manufactured grinding stones. However some useful information was obtained from Ramon Ramos.

It has already been noted that basalt materials do vary in their suitability and ease of shaping. Furthermore, it was apparent from Ramon Ramos' comments and from observation of his work area that certain forms were more susceptible than others to breakage during manufacture. While shaping the legs on a basalt metate, for instance, there is greater risk of breakage than when working on any other portion of the grinding stone itself (personal observation). Shaping the legs is also time consuming and increases, however minimally, the weight of the metate, which must be carried to San Mateo from the place of purchase. Even more susceptible to breakage during manufacture is the mano. That this apparently simple cylindrical form is a relatively "high risk" form is reflected both in the higher breakage rate during manufacture, and also in a shorter use-life

of manos compared to metates (Table 3). This suggests that the primary technological constraint in working stone materials is avoidance of long slender forms. Those forms which deviate from a compact round or squarish shape seem to require the greatest skill, time and energy to produce. They also involve greater risk of breakage.

Social Constraints Suggested by San Mateo Data

The effect of social constraints on the morphology of grinding stones in San Mateo seems to be generally similar to the effect of social constraints on material selection. Specifically, only those stones used to grind maize, the primary staple, are morphologically "expensive"--they have legs and associated long cylindrical manos. While the legs seem to some extent to be justified by the increased energy efficiency associated with the induced slope of the grinding surface, it is probable that craft specialization and a regional distribution system are necessary to overcome the extra costs of time, energy and risk associated with the more complex, tripodal metates.

Comparisons of San Mateo Results With Data From Other Sources

Functional Constraints

The examination of San Mateo grinding stones suggests that the most apparent constraint on form results from a concern for the efficient use of human energy. This is reflected primarily in the intentional slope of the grinding surface resulting from

the differential heights of the legs on tripodal metates. The relationship between the size of the grinding surface and the nature of the substance being ground may also reflect a concern for human energy efficiency. Both of these concerns can be considered functional constraints. Another possible functional constraint would be the need to control the substance being ground and any of its by-products. The presence of legs on the tripodal metates of San Mateo may contribute to meeting such a need by allowing the grinding stone to be placed on a surface or over receptacles which assist in control of the ground substance. Evidence of these functional constraints may be found in other ethnographic and archaeological accounts.

The tripodal metates of Mesoamerica generally display some slope of the grinding surface. The Aguacatenango metates are very similar to those of San Mateo, with a rectangular, flat, sloping grinding surface. As in San Mateo, the slope of the grinding surface can be adjusted by placing the hind leg on a post. Extrapolating from data provided by Stromsvik (1931:144), the average slope for modern Yucatecan metates, which are generally placed on a grinding table, is about ten degrees. Aschmann (1949:633) reports an average slope of 20 degrees for the metates of Baja California. Wisdom (1940:145) does not give the angle of slope for metates among the Chorti, but he does note its existence, attributing it to the need to drain off grinding water. Where a grinding stone has been shaped without legs, and with an even slightly rounded bottom surface (as in

plano-convex forms), a flat surface such as a table should provide an unstable surface and not allow for a slope. In Aguacatenango, however, at least one prehistoric grinding stone was used on a table, with the proximal end propped up on a post (Fig. 7). Both Kidder and Thompson have suggested the possibility that these round bottomed metates were placed in the ground, providing stability (Kidder 1947:33; Thompson 1939:173). Ethnographic data concerning plano-convex metates, where available, suggests that they were often used on the ground, with the near end raised to achieve the desired slope by placing it on a small rock or cobble (Soustelle 1937:37). Bartlett's work in the American Southwest details the progression over time from a rather casual propping of the grinding stones on cobbles to the development of the mealing bin (Bartlett 1933:5-7). The mealing bin--which is a highly sophisticated grinding artifact--includes a grinding slab set into the floor with an average slope of 30 degrees (Bartlett 1933:15). In the Old World, Egyptian terracotta figurines suggest that grinding stones were often set at a slope of about 15 degrees. Flat grinding stones in Asia Minor may have been banked up with earth in order to achieve the desired slope, and Athenian grinding stones were apparently sloped, as well (Moritz 1958:29, 19-20, 38-39).

Comparative data in the ethnographic literature concerning the possible relationship between grinding stone size and function is minimal. This is almost certainly due to the lack



Figure 7. Prehispanic Plano-Convex Grinding Stone with Proximal End Placed on Post: Aguacatenango

of attention given to variation in grinding function, as there is evidence of variation in grinding stone size. Pozas (1959:100) mentions that two sizes of metates were made in Chamula, but gives no indication of why. The average dimensions he gives result in surface areas that look comparable to the San Mateo data (Tables 5, 6). Stromsvik (1931:151) mentions that small metates were made for grinding chile in Northern Yucatan, but does not give any measurements. In contrast to the ethnographic literature, the archaeological literature contains a number of references to at least two size classes of grinding stones (Coe 1959:34; Kidder 1947:33; Kidder et al 1946:140; Stromsvik 1931:146-151; Willey et al 1965:453-456). Supporting the suggestion that the two sizes were used for different grinding functions is the tendency for them to be made of different materials (Coe 1959:34; Kidder 1947:33; Kidder et al 1946:140).

Control and collection of the grinding product and/or by-products may be a more important constraint in the design of grinding stones than suggested by the San Mateo data. Among the Chorti, there is a rim around the edge of the grinding surface of the metate and the ground maize is collected in a container placed at the far end of the metate (Wisdom 1940:88-89, 145). A similar rim occurs on metates in Baja California (Aschmann 1949:683). The mealing bins of the Hopi, in addition to having upright sides, have a plastered surface around the edge of the grinding slab that includes a collection area at the far end

Table 6. Grinding Stone Measurements from Several Regional Centers

Regional Center	Mean Length (in cm.)	Mean Width (in cm.)	Surface Area (in sq. cm.)
N. W. Guatemala (McBryde 1947:61)	38.5	30.5	1174.25
Chamula (Pozas 1944:100)	42.0 32.5	28.5 20.5	1193.00 666.25
Tzotzil Maya (Vogt 1969:59)	40.0	28.0	1120.00
Yucatan (Stromsvik 1931:144)	40.00	22.5	900.00
Baja California (Aschmann 1949:683)	45.0	30.0	1350.00
Southwest (Bartlett 1933:14)	35.0	33.0	1155.00

(Bartlett 1933:15). Bartlett notes, for the American Southwest, that trough shaped metates were used on the floor because the trough prevented spillage (Bartlett 1933:17). Collection areas are also evident for grinding stones from Egypt and Asia Minor (Moritz 1958:30,38-39).

While concern for control of the ground substance may be a common constraint, control of the water used in grinding is a problem primarily where maize has been precooked. Among the Chorti Maya, the grinding table was specially designed to control and collect the grinding water (Wisdom 1940:136-137).

Throughout Mesoamerica, where grinding stones are often tripodal and maize is precooked before being ground, the maize grinding metate is often placed on a table or raised plank (Redfield & Villa Rojas 1962:36; Soustelle 1937:66; Villa Rojas 1969a:231,235; 1969b:207; Duby & Blom 1969:285; Wisdom 1940:88). Slab shaped grinding stones may be raised off the ground in forked sticks, as among the Xinca of Guatemala (Clark 1981: pers. comm.), but this would then make collection of the ground meal more difficult. Although there is insufficient data from other areas for adequate comparison, it is possible that the practice of precooking maize and the use of water during grinding have encouraged the use of grinding tables. Certainly, placing the metate on a table would keep it out of the mud. This, in turn, would have made tripodal metates more desirable, inasmuch as the feet would provide a more stable base on a flat surface such as a table.

Adding a rim around the grinding surface may aid in control of the substance being ground. However, this can have other, less desirable consequences, as is brought out in Bartlett's discussion of Southwestern mealing bins. A raised rim around the grinding surface forces the mano to be held in a position directly over the lower stone. Care must then be taken to avoid contact between the fingers and the lower stone or the woman doing the grinding may scrape her fingers. Among the Hopi, the problem is sufficient for women to have very strong preferences concerning the shape of the mano (Bartlett 1933:15-16). If the

rim around the grinding surface is removed, the mano can be longer than the width of the grinding slab, and held at the ends away from the surface of the lower stone, as in San Mateo and Aguacatenango. In terms of the shape of the grinding surface and its interaction with the grinding process, then, there are two contradictory or counteracting constraints: preventing loss of the ground meal, and preventing damage to the fingers.

Throughout Mescamerica the concern for physical trauma appears to have had minimal impact on the design of grinding stone morphology. In addition to the modern maize grinding metates with rims, most prehispanic grinding stones had a raised edge of some sort, either the slight edge of plano-convex grinding stones, or the more pronounced rim of trough shaped grinding stones. Grinding stones with flat surfaces were usually the tripodal metates. In some, but not all, instances manos associated with these flat surfaced grinding stones were longer than the width of the stone (Kidder et al 1946:Fig. 158; Proskouriakoff 1962:Fig. 21; Woodbury & Trik 1953:223-224). While the rim of most prehispanic grinding stones may have resulted from wear while using a mano that was shorter than the width of the grinding surface, its presence would still have resulted in the same problems and benefits as an intentionally designed rim. Interestingly, Willey *et. al.* (1965:456) note that for the Late Classic and Postclassic Belize Valley a number of grinding stones have a highly polished, beveled edge. They suggest this intentional finishing of the edge might have

reduced the amount of trauma to the hands. One other possible archaeological indication that damage to the hands was a concern occurs in the Old World. A number of handstones from a Classical Greek site have been modified from earlier forms to include either handles or finger grips (Moritz 1958:40-41; Storck and Teague 1952:73). Unfortunately both the dating of this site and the context of the grinding stones are ambiguous (Runnels 1981a:121-122;Moritz 1958:40-41), forestalling attempts to explain the appearance of the modified handstones.

Technological Constraints

Turning to the technological constraints on grinding stone morphology there was the suggestion from the San Mateo data that long slender forms were undesirable due to the increased risk of breakage. Some support for the first constraint comes from modern stone sculptors, who state that the most difficult forms to carve are those involving delicate projections and deep undercuts. The best shapes for carving are those which remain rounded and compact (Rich 1947:214-215). While this seems to have little deterrent effect on present-day metate makers there is some archaeological evidence that both material and technology have in the past acted as constraints on the form of grinding stones. Proskouriakoff (1962:338) has suggested that the present-day tripodal metates of limestone in the Yucatan may be a post-contact phenomenon, perhaps because the introduction of European metal tools made the stone easier to work. Elsewhere, prior to the Conquest "legs" on tripodal metates

originally tended to be very small, and were often restricted to specialized--possibly ritual--use (Borhegyi 1965:26-27; Kidder et al 1946:140). As for material, most pre-contact tripodal grinding stones are made of volcanic materials (Borhegyi 1965:26-27,37,51; Shook 1965:182). A few tripodal metates made of sandstone and schist do occur archaeologically (Stromsvik 1937:126; Kidder 1947:33), but they are relatively uncommon.

Social Constraints

So far the comparative data reinforces the importance of increased energy-efficiency by means of a sloped grinding surface as a functional constraint on grinding stone morphology. However, the particular morphological means of achieving that slope show considerable variation. Similarly, there appears to be some support for the importance of control over the substance being ground and any of its by-products, but the morphological effects of this concern show considerable variation. At least some of the morphological variation in solving functional problems may be attributable to differing socioeconomic contexts and the interaction of different constraints. This may be particularly true for the technologically difficult forms, such as the long slender manos, and the legs of the tripodal metates.

While the legs (or at least the hind leg) of Mesoamerican tripodal metates provide an initial slope as well as a means of adjusting the slope, plano-convex and trough shaped grinding stones can also be sloped by the simple expedient of propping up one end. Within hispanic Mesoamerica, the distinction between

the presence or absence of legs is related to craft specialization and regional marketing. Among the Lacandones both tripodal and legless grinding stones were used. The latter were found in contexts where users had limited trade contacts with markets supplying the specialist-made metates (Soustelle 1937:37). Similarly, where basin shaped and tripodal metates co-occur among the Xinca of eastern Guatemala the basin shaped metates are locally made while the tripodal metates are imported. The tripodal metates, perhaps because they are imported, confer more social "prestige" on their owners than do the basin shaped metates (Clark 1980:12, 26-27). Within the archaeological record the initial appearance of legs (which were all relatively short) in the Highlands was associated with "ritual" metates placed in burials (Borhegyi 1965:26-27; Kidder et al 1946:140). Whatever their use or the reason for the small feet, these small metates would appear to have had an associated prestige value. This association of legs with prestigious special use seems to be continued to the Postclassic, when the single hind leg became considerably elongated (Woodbury & Trik 1953:221). In spite of their prestige value, however, the widespread appearance of legs on grinding stones from known domestic contexts does not occur until after the Conquest, when metal tools and improved transportation are available. Thus the present day maize grinding metates of Mesoamerica may reflect a unique combination of factors. The legs have some functional advantages, particularly where maize is precooked before

grinding. They also have a long-term association with social prestige. Finally, the introduction of European metal tools and improved transportation, in conjunction with the already established craft specialization, would have reduced the technological constraints to the extent that the functionally and socially desirable tripodal metates became generally available for domestic use.

Another instance of morphological variation resulting from the interaction of multiple constraints may be seen in grinding stone dimensions. Although the size of the total grinding surface area seems to be related to function, even a casual inspection of average length and width measurements of metates from areas other than San Mateo suggests that considerable variation occurs in these measurements and in their ratios (Table 6). A comparison of San Mateo and Aguacatenango tripodal metates is interesting in this respect. There is no significant difference in the size of the grinding surface areas in the two populations (Table 7). That is, there is no real difference in the total size of metates from the two villages. There is, however, a significant difference in the length/width ratios, with the metates from Aguacatenango being somewhat longer and narrower (Table 7). This suggests that as long as a sufficient grinding surface area is provided, there may be considerable latitude in the length/width ratios, which in turn is most likely related to source of manufacture and thereby to social group preferences.

Table 7. Comparison of Sizes of Tripodal Metates: San Mateo and Aguacatenango

	San Mateo	Aguacatenango	Student's t *a
Mean Surface Area (in sq.cm.)	1083.30 ($n=69$) ($s=277.89$)	1160.43 ($n=61$) ($s=307.52$)	1.480 ($df=128$) ($p>.05$)
Width/Length Ratio	.7645 ($n=69$) ($s=.0075$)	.6790 ($n=61$) ($s=.0113$)	50.1339 ($df=128$) ($p<.05$)

*a: In both instances, two-tailed tests were used.

Discussion of Constraints on the Morphology of Grinding Stones

The questions posed at the beginning of this section on morphology were how the different constraints of function, technology, and social organization related generally to grinding stone form, and in particular to the tripodal form found only in Mesoamerica. One of the more obviously consistent constraints on grinding stone morphology is function, in the sense of increased energy efficiency. While this would seem to correspond to the importance of functional constraints on material selection, it should be stressed that the nature and effect of the constraints differs significantly in the two situations. Variation in material appears to be rather closely related to improved effectiveness of grinding, or to the characteristics of the substance being ground. In contrast, increased energy efficiency of use is only one of the factors leading to morphological variation. For example, the apparently

world-wide solution to increasing energy efficiency by placing the grinding surface at a slope can be achieved by more than one morphological means. In other words, there is no single optimum morphological solution to any given adaptive problem. The lack of a single optimum solution to a problem is most apparent in the various means of controlling the ground substance and its by-products, the other functional constraint on grinding stone morphology. In some instances a rim is a part of the grinding stone. In other instances control is provided as part of the total grinding environment, either walls external to the grinding surface or, in the case of footed forms, placing the grinding stone on a surface other than the ground.

One of the reasons for the lack of a single optimum solution to a problem is that morphological variation appears to reflect the interaction of multiple constraints. For example, the size of the grinding surface area may be related to functional concerns of energy efficiency, both in the sense of the bulk of the material being processed and in the sense of procurement and storage costs. Within this functional constraint, however, there may be considerable latitude for variation in the length/width ratios, and the preponderance of any particular ratio may reflect a tendency towards social conformity within a given producing or using community.

Part of the answer to the second question raised at the beginning of the discussion of morphology, what constraints can account for the uniquely Mesoamerican tripodal metate, seems

also to be related to the interaction of constraints. Some functional benefits can be attributed to the presence of feet. For instance, they allow the metate to be placed on a surface other than the ground, while maintaining stability. This in turn provides alternative means for adjusting the slope of the grinding surface and controlling the ground substance. The latter may be of greater importance where maize is precooked and water used in the grinding process. These benefits alone, however, do not seem sufficient to justify the technological costs of the legs. The long-term association of legs with social prestige may also be important in enhancing their desirability sufficiently to justify their extra expense. Finally, the reduction of technological constraints with the introduction of metal tools and improved transportation also seems to be necessary. Thus, all three sources of constraint, functional, social, and technological, are related to the present occurrence of tripodal metates.

While the interaction of multiple constraints may account for legs on the tripodal metates of Mesoamerica today, it does not explain their original appearance during the Formative. It is generally assumed that they were used to grind ritual maize, probably in part because of the lack of recognition of variation in substances processed on grinding stones. As has been noted, the earliest footed forms tended to differ from domestic grinding stones not only in form, but also in size and material, all of which suggest that whatever was being processed on them

differed in some significant respect. For the present the question of what they were used for, the reason for the small feet, as well as the reason for the prestige associated with them should all remain open. They may well have been used for the ritual grinding of maize, but this should be demonstrated, not assumed.

This section on grinding stone morphology can be concluded with a restatement of two major points. First, although the concern for human energy efficiency seems to be a fairly universal constraint on grinding stone morphology, there is no single optimal morphological means of meeting that constraint. In fact, the solution to a particular functional problem may not even be directly expressed in the grinding stone form. This leads to the second, and perhaps most important conclusion, that morphological variation must be accounted for in terms of the interaction of multiple constraints, rather than being attributed primarily to one type of constraint, such as function. In this respect morphological variation differs from material variation which is primarily related to variation in function and the economic importance of that function. This should not be surprising given that artifact morphology is produced by the cultural modification of natural forms, while artifact materials, at least in traditional societies, tend to be the most appropriately available materials which can be selected from the natural environment.

IV. CONSTRAINTS ON THE NUMBER AND LOCATION OF GRINDING STONES

In addition to material and morphology, spatial location and number of artifacts are important sources of archaeological information, deserving of analytic consideration. Although beyond the bounds of the design problem these data can be treated using the same approach as the data concerning material and morphology. Functional and social constraints can be considered the independent variables and their relative influence on the dependent variables, location and number of grinding stones, can be assessed. (Technological constraints are omitted from consideration, as they do not appear to have any significant effect on grinding stone distribution.)

The fact that distributional factors are outside the realm of the design problem does create some analytic problems not previously encountered. Two problems in particular are the nature of the sampling unit, and the distinction between archaeological and cultural (systemic) contexts. Where material and morphology are the dependent variables under analysis, the grinding stone itself is the most logical sampling unit. With distributional data the sampling unit will vary with the research goals and design. In the present study, the sampling unit was the household. For the single village site this is reasonable since in many respects the household constitutes a behavioral unit distinct from, yet replicated by other households in terms of the range of activities performed.

However it should be borne in mind that the household is also a social unit, and will bias the interpretation in the direction of social factors.

The second problem concerning distributional data, that of possible disparity between archaeological and cultural contexts, was not a significant aspect of the present study and little effort was made to collect pertinent data. Nevertheless it is an important issue in archaeological theory and interpretation, one that remains unresolved (Schiffer 1972; Brooks 1982). What data are available will be presented, primarily in the hope that they will suggest directions deserving of future study.

In the following section consideration will be given first, to the effect of functional constraints on the location and number of grinding stones; second, to the effect of social constraints; and third, to the visibility in an archaeological context of patterns noted in the cultural context. As in previous sections, the initial discussion will be based on data from San Mateo, followed by a comparison with data from other sources and finally by a general discussion.

Functional Constraints Suggested by San Mateo Data

Function had an obvious effect on the location of grinding stones, with frequency and convenience of use as major considerations. For instance, washing stones occurred most frequently near communal water sources. Of those found in household compounds, the majority (six of seven) were located near springs or streams. One, however, was stored in a house

for reasons unknown. Herb stones which occurred in household compounds were also generally near a water source, although in at least two instances they were found in compounds without a water source. Other special purpose stones, such as those used for grinding coffee, salt, or calcite, were normally kept in the house, stored against a wall or in the attic. In the house only the maize grinding metates, used on a daily basis, were left in place on the grinding table where they were used.

The effect of function on frequency of grinding stones was most obvious at the village level of analysis. Specifically, nearly every household had one or more maize grinding metates, whereas only 26, or about half the households, had special purpose grinding stones. This, again, is a reflection of the greater functional importance of the maize grinding metates for all households in the village. The same consideration of relative economic importance does not seem to be related to the presence or absence of special use grinding stones at the household level. At least one informant who owned a special use coffee grinding metate said that she did so in order to avoid mixing flavors. Other households, however, reported that they simply washed the maize grinding metate after having used it for other purposes. Also, most potters in San Mateo stated that they used their maize grinding metates to grind the calcite temper, even though it was recognized that this reduced the use-life of the metate.

Social Constraints Suggested by San Mateo Data

Social constraints, unlike functional constraints, seemed to have the greatest influence on the frequency of grinding stones, particularly at the household level. In many households two or three metates were obviously in everyday use.

Consistently, when people were asked the reason, the response was that there were two or three women. Each woman owned her own metate, and it was generally not used by other women. There is a significant correlation between the number of adult women (14 years of age and older) per household and number of modern tripodal metates per household, but this unfortunately accounts for only 31% of the variation in number of metates ($r=.5561$, $p<.01$). The number of metates per household is somewhat more closely related to household family structure, with extended families more likely to own two or more metates (Table 8). The association of family residence type and the presence of multiple grinding stones per household is even more strongly reflected in the ownership of special purpose grinding stones. Of the 26 households with these special purpose stones, 21 were extended families, while only five were nuclear families (Chi Square=7.3714, $p<.01$).

One of the reasons the association between the number of metates and number of adult women is not stronger is due to the flexibility in work organization afforded by extended family residence and the subsequent variation from household to household. In some--but not all--extended family households it

Table 8. Household Family Type and Number of Metates: San Mateo and Aguacatenango

Village	Family Type	Number of Metates		Median Test*	Cramer's Phi
		Less Than Two	Two or More		
San Mateo	Nuclear	15	4	p<.01	.6271
	Extended	5	27		
Aguacatenango	Nuclear	6	13	p>.05	
	Extended	3	28		

*The median for both San Mateo and Aguacatenango was two.

would appear that the wife or widow of the head of the family is exempted from maize grinding. In some other households, unmarried adult women may not own a metate and thus distort the association.

Another factor that distorts the relationship between the number of metates and the number of adult women is the storage treatment of metates. Ten of the households surveyed had 15 whole metates in storage. The metates were being stored for a variety of reasons. Two were being kept by a woman for a friend who was away for an extended time, "so they won't be stolen". Another family had purchased at least one metate when returning from the finca, keeping it for future need. In another case an elderly Ladino woman still kept the metate given to her by her husband's mother, although it was seldom used. While storage behavior would distort the relationship between number of metates and demography, it did not alter the relationship between multiple grinding stones and family residence patterns.

Of the ten households with basalt metates in storage, eight were composed of extended families.

The storage treatment of basalt metates was in part a reflection of their value. Although this value derives ultimately from the importance of the metate in the subsistence economy, it can be partially expressed in monetary terms. The approximate price of a metate in the urban market where most were purchased was US\$20. This must be paid from a median annual income of US\$540, or about 3.6% of the cash income. (A comparable example in our society might be the purchase of a new car--with cash.) This raised the possibility that the number of tripodal (purchased) metates might be related to annual income. However, there was no significant relationship between annual income and number of metates per household ($r=.2654$, $p>.05$). The lack of relationship between annual income and ownership of grinding stones extends to special purpose stones as well, where it would be even more reasonable. In particular, of the six tripodal metates used for salt grinding or as toys which, because of their small size, would have been purchased intentionally for special use, only one belongs to a household whose annual income is higher than the normal range of variation, while two belong to households with annual incomes below the sample median.

There were five households in San Mateo which did not have even one metate. Although each of the five households differed, they may provisionally be grouped into two categories,

households which were socially unique, and households in a state of transition. The first group included two single women. One was the local equivalent of a scarlet woman, who lived by begging. The second woman was at the other extreme of the social scale. She was the Alcalde Rezadora, widow of the life-time head of the religious cargo system. Like her husband before her she was forbidden to work and was also dependent on the charity of her neighbors. The other three households without metates were those whose members were part of an extended family undergoing physical separation of residence, although the process was incomplete and at least some meals were taken in the original household.

For the most part household family structure was the only social variable associated with the presence and number of grinding stones. The one exception was for herb preparing artifacts. In addition to an extended family household, the presence of herb preparing artifacts was associated with adherence to traditional religious beliefs (Table 9). For purposes of analysis herb mashing stones and wooden herb mashing mortars were combined to provide a reasonable sample size. This was considered justifiable since, as noted earlier, the distinction between the two in San Mateo appeared to be primarily a matter of personal preference. In San Mateo traditional religious beliefs and practices are essentially Mayan, with a very thin veneer of Catholicism. They may be contrasted with non-traditional religious beliefs and practices,

Table 9. Herb Preparation Artifacts and Associations:
San Mateo *a

Household Trait	Herb Preparation Artifacts		Distribution Statistics
	Present	Absent	
Religious Affiliation (<u>n</u> =47)			
Traditional	9	16	p=.0315 *b
Non-Traditional	2	20	Phi=.3171
Number of Herbs Used (<u>n</u> =45)			
Under Four	3	9	p>.50 *c
Four or More	10	23	

*a Herb mashing stones and wooden herb mashing troughs were grouped together in order to increase the sample size. Since the choice between stone and wood appeared to be a matter of personal preference, this was felt to be justifiable.

*b Fisher's Exact Probability Test

*c Median Test. Range=0-8, median=4.

either in the form of Evangelical Protestantism or reconverted Roman Catholicism. The association of traditional religious affiliation and herb preparation artifacts reflects the close relationship between religion and medicine in traditional Mayan thought (Roys 1965:ix). Another variable which might be expected to be associated with the presence of herb preparation artifacts is the extent of reported knowledge of herbal use. This, however, was not the case (Table 9). The association of herb preparing artifacts with religious affiliation, but not reported knowledge of herbal use, provides strong support for the possibility raised earlier of an association between the

ideologically important green-colored stone and herb mashing, at least in the Maya area.

Archaeological Visibility of the Systemic Context Suggested by San Mateo Data

Although functional and social constraints are related to the distribution of grinding stones in the cultural context, the questions remain, first, to what extent this patterning would be maintained in the archaeological record, and second, to what extent it would be recognized. The latter is primarily a sampling problem. For example, where the location of grinding stones in San Mateo seemed to be determined primarily by convenience of use the focus on the household as the sampling unit resulted in certain special use grinding stones being underrepresented in the material inventory. In particular, clothes washing stones and herb mashing stones were often not associated with structures and their surrounding compounds and were therefore not recorded. The effect of similar biases in archaeological sampling would be more difficult to detect.

It is reasonable to expect some alteration of the distributional patterns in the development of the archaeological context from the cultural system. For example, given the high value--both functional and economic--of the maize grinding vesicular basalt metates, it seems unlikely they would be abandoned with a house or site. The storage of two metates by a woman whose friend was away at the finca would lend credence to such an expectation, although the woman at the finca had only

temporarily abandoned her house, and her treatment of the metates might more reasonably be considered caching behavior in expectation of her return. The value of metates might also be expected to affect their treatment when broken or damaged, with the possibility that useable fragments would be reused for other purposes and discarded in situ at the time of abandonment. It is true that when a metate breaks large fragments may be kept for special purpose uses. Smaller fragments, however, were generally discarded in a nearby dump, and large fragments were not common. Only five of the basalt metates inventoried were fragments, four of which were used to grind coffee, and one to grind salt. Of the metates used to grind maize only one was damaged, with a leg missing. This was in a household which also had a large basalt fragment for special use.

Comparisons of San Mateo Results With Data From Other Sources

Based on the data from San Mateo, it would appear that the constraint which most closely influences the location of grinding stones is function. Those stones used for food preparation are found in the house, while grinding stones for other uses are located at the most convenient place of use. This may seem obvious, and in fact has been an implicit assumption for much archaeological interpretation.

The constraints influencing the frequency of grinding stones seem to vary depending on the level of analysis. Functional constraints appear most important at the village level of analysis, with the preponderance of maize grinding

metates reflecting the importance of maize grinding in the subsistence economy compared to other grinding functions. On the other hand, social constraints, including household residence patterns and ideological associations appear to be most important at the household level of analysis, perhaps reflecting the social nature of the household unit. Extended family households were most likely to have two or more maize grinding metates, and were also most likely to have special purpose grinding stones. In addition, the presence of herb washing stones or mortars appears to be related in part to adherence to traditional religious beliefs. As for the archaeological record, information concerning the relationship to the cultural system is extremely limited. Both the discard of broken metates and the storage (or caching) of metates during temporary absence suggest that distribution of the vesicular basalt maize grinding metates would undergo significant distortion in the transformation process.

Comparable data in the ethnographic literature concerning the location and number of grinding stones are extremely sparse. There is some indication that maize grinding metates are not restricted to the inside of the house but may occur in the compound as well (Soustelle 1937:66; Stromsvik 1931:Plate 1; Wisdom 1940: facing 88). In either situation, however, the stones used for grinding food are located in proximity to the house.

Given the general lack of recognition of variation in grinding stone functions, it is hardly surprising that no mention is made of alternate locations for special purpose grinding stones. There is some photographic evidence that washing stones tend to be associated with streams or other water sources (Nash 1969:40; Tax & Hinshaw 1965:74-75). In Aguacatenango clothes were washed at nearby streams or in the lake, although wooden washing tubs were used in place of washing stones (Deal: pers. comm.). As noted earlier, the association of washing stones--or boards--and sources of water is to be expected. It does reinforce the suggestion, however, that similar artifacts may be as underrepresented in archaeological assemblages as in the ethnographic record. Since herb mashing stones tend also to be located near a water source in San Mateo, their presence in archaeological assemblages may be equally underrepresented. A possible exception might be the green metate at Seibal (Tourtelot 1970:412).

Comparative data concerning the relationship between the number of grinding stones and household residence patterns is available from Aguacatenango. As in San Mateo, the median number of metates per household was two. Unlike San Mateo, over half the households in Aguacatenango owned two metates, irrespective of family residence structure, and the relationship between number of metates and household residence type was not significant (Table 8). There is some possibility that this may be a reflection of a change in the function of the extended

family household. While there is no significant difference in the proportion of extended versus nuclear family households for San Mateo and Aguacatenango, there are some differences in the composition of the extended family household. In San Mateo all extended families were composed of a couple (or the surviving widow), their married adult children, and offspring. In Aguacatenango seven of the extended families included a divorced daughter with her children. In other words, there may be a tendency in Aguacatenango for the extended family household to be more an economic convenience for individual members rather than a cohesive socioeconomic group.

In the American Southwest Martin (1972:57) has used change in the number of grinding stones per household, along with several other changes, to suggest change in social organization. Using the historic pattern as a model, he argues that a set of three grinding stones in a single room represents a single family household. When the number of grinding stones per room is greater than three, he assumes it reflects an aggregation of families sharing the same residence. Unfortunately, the single family of the historic period on which Martin's model is based is generally an extended family, not a nuclear family (Eggan 1950:29, 146, 188, 232, 262; Mindelleff 1891:212; Winship 1896:522). Whatever the reasons for the change in number of grinding stones it is not related to a shift from nuclear to extended families. In short, family residence patterns may well be related to the frequency of grinding stones per household, as

in San Mateo, but the Aguacatenango and Southwestern examples suggest that this relationship may be influenced by other factors.

One of the factors which may affect the relationship between family residence and the number of grinding stones is the influence of the regional socioeconomic system on the function of the extended family. As has already been noted, one of the effects of extended family organization in San Mateo was an increase in the options in scheduling time and activities of individual members, specifically of women engaged in maize grinding. For a relatively isolated, self-dependent community, such as San Mateo, this low order of specialization may allow the extended family household increased opportunities for acquiring additional or special purpose artifacts. The alternative explanation, that greater economic resources are available to the extended family, does not hold for San Mateo, where neither wealth nor income are related to family residence.

In contrast to San Mateo, Aguacatenango is much more integrated into a regional economic system, as will be discussed more fully in the following chapter. One possible consequence has already been noted for Aguacatenango, the presence of divorced women and their children as part of several extended family households. Another consequence is that ease of access to a variety of artifacts, including maize grinding metates, is increased. This increased ease of access almost certainly overrides any benefits of time and energy which might be

afforded by low-level specialization within an extended family.

Ethnographic evidence that metates in good condition might be removed from a house or site at abandonment does exist, although it, too, is extremely sparse. Lange and Rydberg (1972:430) record the selling of a mano and metate by a widow moving from a rural subsistence household to an urban center in Costa Rica. Wagley (1940:30) notes that families in the Guatemalan Highlands going to work on the fincas for a season took their grinding stones with them. This is in contrast to less sedentary groups who left their grinding stones at the site where they were used, awaiting the subsequent return of that group (Gould 1980:26; Kraybill 1977:491). This is rather like the San Mateo woman who stored her metates with a friend until her eventual return.

Archaeological data concerning grinding stones, as already noted, are problematical, due both to inadequate reporting (Longyear 1952:105) and to biased sampling (Kidder 1947:2). Even so there is some variation in the archaeological record, and presumably therefore in the processes leading to that record. Flannery and Winter (1976:37) note that in Formative villages of Oaxaca every household group had fragments of grinding stones, but only two complete manos and metates were found. Both of these were found in or next to a small bell-shaped pit which contained a number of other artifacts. Borhegyi (1965:8-9) also mentions the fact that manos and metates are found in storage pits for the Early Formative in the

Guatemalan Highlands. At least one mano and metate were found in a Late Formative housemound at Uaxactun (Coe 1959:35), while in the Belize Valley fragments of manos and metates were found in nearly all excavated housemounds from the Formative on, either as fill or as floor debris (Willey et al 1965:452-453). Turning to the Southwest there is some evidence that during late prehistoric periods grinding slabs were sometimes deliberately retrieved from mealing bins rather than being abandoned (Bartlett 1933:24-25). Evidence for similiar treatment does not occur for earlier periods. Martin (1972:56) also notes a general decline over time in the total number of grinding stones per site, irrespective of--or even in inverse relation to--the number of households.

Although the data are extremely sparse, they do suggest that constraints affecting treatment of grinding stones at the time a site is abandoned may vary with the economic and cultural context. In particular, economic importance of the grinding stone, expectations regarding future use of the site, and the extent of sedentism of the social group may all affect the archaeological visibility of grinding stones. For example, increased economic importance of the grinding stone may restrict its archaeological visibility, while a subsistence economy based on a seasonal round may increase the archaeological visibility of grinding stones. The pit storage of manos and metates during the Formative of Mesoamerica may reflect the transition from their growing importance during a time when villages were still

only occupied on a semi-permanent basis.

Discussion of Constraints on the Location and Number of Grinding Stones

The decision to look at the constraints influencing spatial location and frequency of grinding stones was based on the fact that such data are a major source of archaeological interpretation. There was some indication from San Mateo that functional constraints influenced location of grinding stones, as well as the relative proportion of different types of grinding stones for the village as a whole. Social constraints appeared to have more effect at the household level, with family residence patterns related to both the number of maize grinding metates and the presence of special purpose grinding stones. Comparison with the sparse data from other sources suggests that functional considerations of convenience of use do influence the location of grinding stones, but only in a rather general fashion. The relationship between family residence pattern and number of grinding stones was even less consistent. In other words, the factors influencing the distribution of grinding stones in the cultural context are as yet relatively unknown. Furthermore, the manner in which this distribution is transformed to an archaeological context may vary depending on a number of factors, including the economic importance of the grinding stone and the permanence of occupation of the site.

Although the data concerning the relationship of grinding stone distribution in the archaeological record and in the

cultural context are extremely limited, some points deserve further comment. First, more attention needs to be given to constraints affecting distribution in the cultural context, how it varies, and under what conditions. Second, the transformation processes resulting in the archaeological record may also vary from one cultural system to another. Understanding is needed not only of conditions related to variation in the disposal of refuse, but also of conditions related to variation in storage, caching, and transportation of useable artifacts. Finally, it should be apparent that the constraints influencing the distribution of grinding stones in the archaeological record are at least as complex as those influencing the form and material of the same grinding stones. However the attributes resulting from the latter constraints undergo fewer distortions in the transformation of the cultural context to the archaeological context so that the understanding to these constraints may ultimately provide a more secure interpretive data base.

V. MODERN INFLUENCES ON THE TREATMENT AND USE OF TRADITIONAL GRINDING STONES

The influence of various constraints on material selection, form, and distribution of grinding stones can be demonstrated for San Mateo, and to some extent for Aguacatenango. In order to apply the inferences or conclusions from this analysis of modern ethnographic data to archaeological material, however, the impact of modern (i.e., European) technology and its effects must be considered. As was pointed out in the beginning modern grinding technology is present in both San Mateo and Aguacatenango. The problems to be dealt with in this section include the extent that modern technology has modified the traditional treatment and use of grinding stones, and in what ways. The question of modern influence, like that of distribution, is not, strictly speaking, within the framework of design theory. In order to maintain consistency, however, it will be approached within the same structure of functional, technological, and social constraints. In particular, attention will focus on the apparant diseconomy of maintaining multiple maize grinding implements. The comparative section will focus on the differences between San Mateo and Aguacatenango, and the fact that in Aguacatenango the entire grinding technology is attenuated compared to San Mateo.

Functional Constraints Suggested by San Mateo Data

In addition to using metates, most of the women of San Mateo also made regular use of the motor-driven mills. These have a number of virtues, the primary one being that they reduce the amount of time required to grind the cooked maize from three-to-four hours per day to about half-an-hour per day (Table 4). For users they also do not require any initial capital expenditure, and they have a potentially infinite use-life. On the negative side, they require a daily flow of petty cash of US\$.05 per day. At the end of a year, this amounts to US\$18.50.

Another possible alternative for grinding maize is the hand-cranked metal corngrinder. Eighteen of the households inventoried in San Mateo had metal corngrinders, although they were being used in only ten households. In six of the remaining households the corngrinders were broken and not replaced, and in the other two they were simply set aside and not used. Even for the ten that were in use, there is some question of the consistency of their use. This has probably biased use-life estimates, which at six-to-seven years seem too high. The cost of purchasing a metal corngrinder was US\$17.00, which is nearly equivalent to the US\$20.00 cost of a metate. Like the motor-driven mill, the metal corngrinder reduces the amount of grinding time required to do the grinding. Furthermore, even with a use-life of two-to-three years it is substantially cheaper in the long run. The major drawback is the initial purchase price.

In view of the above use of the motor-driven mill in combination with the basalt metate would appear to be particularly uneconomic behavior. The combination incurs both a major initial expense plus on-going expenses. Discussion with the owner of the local inn suggested however, that local behavior is more logical than it seems. She must pay hired help to get her maize ground, so she is in a position to evaluate the relative time costs of different grinding methods in monetary terms. She found that it was cheaper for her to patronize the motor-driven mill rather than use a metal corngrinder. In other words, there is a savings of time using the motor-driven mill compared to the hand-cranked corngrinder sufficient to compensate for the increased costs. The final grinding of maize on a stone metate insures that it will be sufficiently fine to make acceptable tortillas. Another woman who owned a metal corngrinder stated that she preferred the motor-driven mill because it was easier, but used her corngrinder when she did not have the necessary five cents.

The positive and negative functional attributes of the various grinding implements may be summarized as follows. Metates give the finest meal, important because it is used to bake tortillas. Metates have a long use-life, and are always available whether or not there is cash on hand. However, they do require a substantial initial investment, and their use is time consuming and laborious. The motor-driven mills are fast and easy, do not require any initial investment or maintenance,

and do not need replacing. They are, on the other hand, the most expensive to use in the long run, require a constant supply of small cash, and do not give a sufficiently fine grind to the meal. The metal corngrinders are faster to use than the metates, and do not require a daily cash supply. They do require more time and energy than the motor-driven mills, a major initial investment, and relatively frequent repair and/or replacement. They also do not give a sufficiently fine grind to the meal. On balance, the combination of metate and motor-driven mill is uneconomic only in monetary terms (Table 10). In every other respect it would appear to be the ideal combination.

Technological Constraints Suggested by San Mateo Data

There are obviously major differences in the technological constraints on the production of grinding stones of whatever material, and on the production of their industrial replacements. For the people of San Mateo, however, the critical constraint would appear to be accessibility, since none are manufactured locally. Accessibility and acceptance of industrial replacements seems to be related to construction of the road since neither metal corngrinders nor motor-driven mills were present until after its construction.

The potential impact of the road on access to metates was also considered. Prior to the building of the road, residents of San Mateo obtained their maize grinding metates either from traveling salesmen, or by carrying them on their backs from a

Table 10. Positive and Negative Functional Attributes of Alternate Maize Grinding Technologies

Attributes	Metate	Mill	Corngrinder
Fine grind	high (+)	low (-)	low (-)
Use-life	high (+)	high (+)	moderate (0)
Daily Cost	low (+)	high (-)	low (+)
Longterm Cost	low (+)	high (-)	moderate (0)
Initial Cost	high (-)	low (+)	high (-)
Labor Cost	high (-)	low (+)	moderate (0)

regional market. With the advent of the road, it became possible to carry a newly purchased metate to San Mateo on the bus. There are at least two possible consequences of the building of the road. The first is an increase in the number of metates. The second is an increase in size of the metates. While the first possibility cannot be evaluated directly the data from the previous section concerning grinding stone frequency suggest that the impact, if any, was minimal. It may have affected the number of metates kept in storage, but is likely to have had little other effect. The second possible impact, an increase in size, was evaluated using grinding surface area as an approximation of size and weight. Metates less than twenty years of age, purchased after construction of the road, were compared with those over thirty years of age. No significant difference between older and younger metates was found (Student's $t=.1430$, $n=31$, $p>.05$). Thus the presence of the road does not seem to have had a significant impact on accessibility of metates. The lack of impact of the road on size of metates corroborates the conclusions reached in the

discussion on grinding stone form, that, within limits, the size of the grinding surface area is determined by function.

Social Constraints Suggested by San Mateo Data

The common positive attribute shared by both the metal corngrinder and the motor-driven mill is the reduction in total grinding time of the maize. While the motor-driven mill offered a greater reduction in time and energy spent grinding this should be most relevant for those households in reasonable proximity to the center of town, where the motor-driven mills tend to be concentrated. For households further away, the time spent walking to and from the mill would presumably counter-balance such benefits. However, there was no significant difference in the distance from town center for all owners compared to all non-owners (Table 11). This is at least partly a reflection of the compact settlement of San Mateo, with five-to-six minutes being the median distance from town center for all households. At the same time, it should be noted that of the four households furthest from town center (between 20 and 30 minutes) three did have metal corngrinders. In other words, distance from the motor-driven mill may be a factor in ownership of a metal corngrinder if this distance is large enough, but this does not account for the majority of the metal corngrinders in San Mateo.

Savings in time might also be a factor for extended families and/or families with several adult women members. Essentially, the more adult women in a household, the more

Table 11. Corngrinder Ownership and Social and Technological Attributes: San Mateo

Technological and Social Attributes	Statistic	Probability
Time Saving:		
Distance from Town Center	Kolmogorov-Smirnov =.9365	>.5000
Family Type	Fisher's Exact Probability	.5464
Cost:		
Cash Income	Mann-Whitney U =220.00	.1291
Income Source		
-Land Based	Mann-Whitney U =230.50	.1898
-Craft Based	Mann-Whitney U =253.50	.3887
-Wage Labor	Mann-Whitney U =279.50	.7251
-Service Activities	Mann-Whitney U =202.00	.0543

efficiently food preparation tasks could be divided, thus minimizing the cost in time of the corngrinder compared to the motor-driven mill. The fact that ownership of number and variety of grinding stones is associated with household structure would tend to support such an expectation. However there is no significant association of either number of women or family type and corngrinder ownership for the sample as a whole (Table 11).

While the metal corngrinder and motor-driven mill share the attribute of saving time, they differ markedly in terms of cost and effective use-life. Focusing on the substantial cash outlay

required to purchase a metal corngrinder, the possibility that only those families with a fairly large cash income would be likely to purchase a corngrinder was considered. The results, again, were negative (Table 11).

Finally, the relationship between source of income and metal corngrinder ownership was considered. The rationale for doing so was based on the fact that the choice between corngrinder ownership and use of the motor-driven mill involved choosing between specific sets of characteristics, and that the particular set of characteristics chosen might reflect the relative importance of similar characteristics in work/subsistence related activities. In particular, it was expected that a high income from wage labor would be most likely to predispose people to acquire metal corngrinders since deriving income from wage labor should lead to an increased awareness of monetary values. Source of income was categorized as follows:

1. Land-based income, primarily from the sale of produce;
2. Craft-based income, from the sale of cottage-industry products such as candles, fibre-products, leather work, and carpentry;
3. Wage labor, primarily from work on lowland plantations;
4. Service activities, such as owning a store or small-scale restaurant, selling a fermented maize liquor, or butchering.

Contrary to expectation, income from wage labor was not related to corngrinder ownership. Of the four categories, income from service activities was most likely to be related to corngrinder ownership (Table 11). Although labeled service activities, these might also be considered entrepreneurial activities, with the individual serving as middleman in the organization and distribution of goods. In the process the individual must assume a major share of the risk, including a willingness to make a significant initial expenditure. Success in such ventures would be particularly dependent on product turn-over as opposed to durability, as well as valuation of monetary gain. These are essentially the same attributes as high purchase price, short use-life, and monetary benefit, the attributes of the metal corngrinder.

Comparisons of San Mateo Results With Data From Other Sources

The primary impact of modern technology on maize grinding in San Mateo appears to be in the provision of a supplementary rather than a replacement technology. The importance of modern technology is in its potential for reducing time and energy spent grinding maize. The fact that it does not replace the traditional stone metates seems to reflect the continued importance of finely ground meal. There is some suggestion that the choice of supplementary technology depends at least partially on the evaluation of alternative attributes, with the evaluative choices to some extent reflecting the differential importance of characteristics of behavior in economic

activities.

The use of modern technology to supplement maize grinding metates is common throughout rural Mesoamerica. Both the importance of reduction in time and energy expenditure and retention of an appropriate meal texture have been mentioned elsewhere (Vogt 1969:58, 59). A similar supplementing of traditional grinding stones with metal corngrinders has occurred in the Southwest, as well. There, in some instances, a partial replacement has also occurred. Because of the use of three different grades of stone texture for the grinding slabs, the metal corngrinder could and apparently did sometimes replace the coarse textured grinding slab (Bartlett 1933:14). This partial replacement underscores the inability of relatively inexpensive modern technological alternatives to achieve a sufficiently fine meal, since it is only the coarse textured stone which is replaced. It also underscores the importance of meal texture as a determinant of grinding technology.

While choice of the motor-driven mill as the supplemental technology is most characteristic of San Mateo, the opposite is true of Aguacatenango where there is almost total reliance on metal corngrinders. Furthermore, informants in Aguacatenango estimated the use-life of metal corngrinders at two-to-three years, rather than the six-to-seven year estimates given in San Mateo. This suggests that metal corngrinders are much more extensively and consistently used in Aguacatenango. Also in contrast with San Mateo, there was only one motor-driven mill in

Aguacatenango, and it was not extensively used. If, as suggested, the difference in choice of technologies with conflicting attributes is related to differences in economic activities, then Aguacatenango and San Mateo should differ in economic activities as well. While there was no significant difference in total annual income for the two villages, there were significant differences in two income sources, wage labor and service activities (Table 12). Income from wage labor was significantly greater for Aguacatenango, while there was minimal income from service activities. While these results are contrary to expectations based on the San Mateo data, they are indicative of a more important difference between San Mateo and Aguacatenango. Specifically, Aguacatenango is more closely incorporated into the modern economic society, and this has had a number of effects on grinding functions and technology.

Research concerning the adoption of new artifacts and behaviors from a wide variety of disciplines, including rural sociology and anthropology, has been summarized by Rogers and Shoemaker (1971). They state that the patterning of adoption of modern artifacts and behaviors by a community depends to a large measure on the extent of extra-community communication and interaction (Rogers and Shoemaker 1971:41, 48). The underlying reason is that the greater the interaction and communication, the more likely people are to be open to and accepting of values and opinions of the outside, donating community or society.

Table 12. Comparison of Economic and Social Characteristics:
San Mateo and Aguacatenango

Social/Economic Characteristics	Village Median	Statistic	Probability
Total Income (US\$/Year)	San Mateo=540.00 Aguacatenango=553.50	Mann Whitney U=1244.50	.8359
Land Income (US\$/Year)	San Mateo=202.00 Aguacatenango=200.00	Mann-Whitney U=1153.50	.4092
Craft Income (US\$/Year)	San Mateo=60.00 Aguacatenango=80.00	Mann Whitney U=1068.50	.1601
Wage Income (US\$/Year)	San Mateo=48.00 Aguacatenango=96.00	Mann-Whitney U=855.50	.0041
Service Income (Number Reporting*)	San Mateo=31 Aguacatenango=6	Chi Square =25.88	<.001
Informant Visits to Other Municipalities (Number/Year)	San Mateo=12 Aguacatenango=75	Mann-Whitney	.0000
Informant Visits to Regional Centers (Number/Year)	San Mateo=3 Aguacatenango=20	Mann-Whitney	.0000
Reported Herb Knowledge (Number Herbs Known)	San Mateo=5-6 Aguacatenango=0	Kolmogorov Smirnov =28.06	<.001

*Few informants in Aguacatenango had income from service activities, so number of reporting households for each village was compared. In San Mateo income from Service Activities ranged from \$0.00 to \$1872.00, with a median of \$25.00. In Aguacatenango income from Service Activities ranged from \$0.00 to \$438.00.

Physically, San Mateo is much more isolated than Aguacatenango. Even with the building of the road, the nearest large-scale modern market center for San Mateo (Huehuetenango) is for most residents at least a two-day round trip, dependent on transportation which is less than totally reliable. For residents of Aguacatenango, on the other hand, a round trip visit to either of two major marketing centers may be easily made within a single day or even half-day, with frequent and reliable transportation. This difference is underscored by the fact that persons from Aguacatenango visit both other villages and other regional centers a significantly greater number of times per year than persons from San Mateo (Table 12). In other words, residents of Aguacatenango are involved in significantly more extra-community communication and interaction than residents of San Mateo. Perhaps most important is the much greater contact and interaction with "Ladino" or Europeanized regional centers. This difference would be reinforced by the greater involvement of Aguacatenango residents in the wage labor market, as well.

One of the characteristics of our modern, cash-based economic society is the extreme emphasis we attach to monetary values. This characteristic would be particularly emphasized in precisely those contexts where traditional and Ladino peoples most interact, the trade and job markets. An increased emphasis on monetary values would favor the use of the metal corngrinder as the industrial supplement in Aguacatenango rather than the

motor-driven mill. Monetary value is the only attribute where the corngrinder is superior to the motor-driven mill. For other attributes, such as effective use-life and dependability, the latter remains superior (Table 11).

The differences between San Mateo and Aguacatenango are reflected in a number of other aspects of grinding technology, most noticeably an attenuated traditional artifact inventory for Aguacatenango. There are no washing stones or herb mashing stones reported, for example.

Use of washing stones is generally not reported in the ethnographic literature, and the fact that it is relatively common in the Guatemalan Highlands is reflected primarily in photographs (Nash 1969:40; Tax & Hinshaw 1965:74-75). There is one reference, for the Chorti, who preferred stones, although wood platters were used by some. The use of wood boards has been attributed to Spanish influence (Wisdom 1940:146-147). The preference for washing stones in the Highlands may be partially due to the abundance of locally available water. However, Aguacatenango is not devoid of streams, and is situated near a small lake. Women in Aguacatenango commonly carry their clothes and wash tubs either to a nearby stream or to the lake to wash their clothes (Deal:pers. comm.). In other words, the behavior and location associated with clothes washing is the same for San Mateo and Aguacatenango, only the artifacts differ. Wooden wash tubs are occasionally reported ethnographically, however Redfield and Villa Rojas observe that in Chankom there was no

Mayan name for them, only a Spanish name (Redfield and Villa Rojas 1969:36). This would lend support to Wisdom's belief that use of stones is the traditional method for washing clothes, with wooden replacements having been introduced by the Spanish. It has also been suggested that the technology of shaping wooden wash tubs prior to the introduction of metal cutting tools would tend to be prohibitive, although washing boards may have been used where stones were scarce as in the coastal lowlands (Hayden:pers. comm.).

The smaller number of herb preparing artifacts for Aguacatenango compared to San Mateo is probably also a reflection of greater accomodation to modern material culture. First, while the Guatemalan government does provide modern medical services to native villages, similiar services have been provided for a longer time and on a more consistent basis by the Mexican government. In this regard it is worth noting that reported knowledge of herbal remedies is significantly less extensive in Aguacatenango compared to San Mateo (Table 12). Second, it will be recalled that the presence of herb preparing artifacts in San Mateo was related to adherence to the traditional form of religion. In Aguacatenango, all households interviewed had adopted either Roman Catholicism or some form of Protestant Evangelism. In contrast, in San Mateo over half of the households interviewed continued to follow the Mayanized form of Catholicism. Thus there are both practical and ideological reasons for a greater continued reliance on herbal

medicine in San Mateo, with a subsequent greater number of herb mashing stones.

A possible third consequence of the relatively greater acculturation of Aguacatenango is the lack of association between family residence and number of grinding stones discussed in the preceding section. It was suggested that the function of extended family residence for San Mateo might be that it allows greater flexibility in work organization within the residence unit. This in turn might be considered a low order of specialization in a relatively unspecialized self-dependent society which in turn allows the increased acquisition of special use artifacts by individual households and their members. For Aguacatenango, on the other hand, it was suggested that there might be a tendency for the extended family household to be more an economic convenience for individual members. This could result from an increase in alternative sources of economic opportunity (or "specialization") for Aguacatenango residents in combination with a slight shift away from a subsistence orientation and towards a market economy orientation.

Discussion of Modern Influences on the Treatment and Use of Traditional Grinding Stones

The multiple methods of maize grinding are an excellent example of the conflict between constraints, and the fact that people must make choices between alternative attributes. Furthermore, choices made by residents of San Mateo and Aguacatenango, both in their similarities and their differences,

support the argument that choices made reflect the problems being dealt with in the broader adaptive environment. For example, in both San Mateo and Aguacatenango, as well as elsewhere, use of the stone metate is retained in order to insure a sufficiently fine meal. Meal texture is a major consideration as long as maize tortillas cooked over a wood or brush fire remain a major staple in the diet. The alternative modern method for obtaining finely ground meal involves multiple siftings and grindings. Thus, stone metates are likely to remain an important item of material culture as long as meal texture remains important. Furthermore, the retention of stone metates at both San Mateo and Aguacatenango reflects the essential traditionality and subsistence orientation of both villages.

A second similarity between San Mateo and Aguacatenango is the use of a supplementary method of grinding in order to reduce costs of time and energy. The two villages differed, however, in which supplementary technology was predominant, and the attributes of the chosen technology corresponded with certain adaptive behaviors related to differences in socioeconomic organization for the two villages. Specifically, preference for the more economical metal corngrinder by residents of Aguacatenango reflects their greater involvement in modern economic society, with the subsequent necessity to place a greater value on monetary factors. This is in contrast to San Mateo, which is relatively more self-dependent and less

integrated into modern society, with the subsequent necessity for valuing time, energy, and dependability as adaptive.

Another consequence of the greater involvement of Aguacatenango in modern society is the attenuation of the grinding stone inventory and replacement with modern material culture. Therefore, it can be assumed that the greater variety of grinding functions and associated artifacts that characterizes San Mateo is more likely to reflect the prehispanic situation in Mesoamerica. In fact, it is likely that greater specialization of function of grinding stones may have existed in the past.

Finally, while the present consideration of acculturation has focused on the impact of modern economic society and technology on two traditional villages, it is important to remember that a major underlying factor was variation in the extent of extra-community communication and interaction. Similar variation has certainly occurred in the past, and has equally certainly affected the material culture inventory, although in what ways must at this time remain an open question.

VI. CONCLUSIONS

In the Introduction it was stated that grinding stones offer considerable potential for understanding both prehistoric lifeways and cultural processes. Much of the foregoing analysis has focused on exploring the relationship between the physical attributes of grinding stones and their cultural context, providing an initial basis for interpreting prehistoric lifeways. In addition, suggestions were made which had implications for understanding the cultural processes of adaptation and evolution. In this section some of the major points made concerning the physical attributes of grinding stones and their implications for interpretation of archaeological grinding stones will be summarized briefly. This will be followed by a discussion of some of the suggestions made concerning the adaptive implications of the analysis.

Physical Attributes

The first, and in some ways the most critical point, is that many grinding functions exist in traditional contexts. This point cannot be stressed too strongly, since understanding and interpreting the variation present in grinding stones cannot occur until the functional variation is recognized and accepted. In San Mateo and Mesoamerica these functions included not only maize grinding, but also grinding roasted beans, coffee, spices, salt, and temper and pigments for pottery; mashing medicinal

herbs; and washing clothes.

The second point is that of the three sources of archaeological information--material, morphology, and distribution--variation in function is most closely related to variation in material. The reason is that people chose material on the basis of its suitability for the intended function. The implications for understanding the function of prehispanic grinding stones (and other artifacts) are considerable. Much more attention needs to be given to understanding materials from which artifacts are made and their functional characteristics. For grinding stones the material attributes that seem to be of greatest importance include texture and hardness. These material attributes are related to such functional characteristics as the characteristics of the substance being ground, the desired fineness of grind, grinding efficiency, and use-life of the stone. The relative importance of various functional characteristics will depend both on the substance being ground and on its subsequent treatment and relative economic importance. For some substances, such as those with a high moisture content, a rough, open texture may be extremely desirable. This would also improve the efficiency of grinding, or the amount of material that could be processed in a given time. On the other hand, a smooth stone texture would be desirable for other functions, such as herb mashing, where the substance being processed is relatively soft and the desired result of processing is pulverization, not grinding. The

importance of a fine meal texture may be more important for grains which are baked rather than boiled, and this in turn may reflect the importance of that grain in the subsistence economy. Finally, use-life of the grinding stone increases in importance as the quantity and economic importance of the substance being processed increases.

One of the implications of the the previous points for archaeological interpretation is that material variation is one of the more potentially useful sources of information available. However, material classification cannot rely on geological categories unless source of material origin is the primary research question. Where research interest is directed towards functional questions, classification should be based on those material properties most relevant to function, such as texture and hardness.

A third point is that while the relationship between function and material is relatively straightforward it is still subject to modification by the cultural context, most specifically by socioeconomic organization. The extent of craft specialization and intercommunity interaction in particular are likely to modify the importance of one or more functional characteristics, and therefore of the importance of material attributes. For instance, the availability of certain desirable material attributes may be limited by the extent of both craft specialization and intercommunity trade relations. Also, use-life may become less important where extensive

intercommunity interaction increases the availability of replacements.

A fourth point concerns morphological variation. While artifact form is often assumed to be related to function, this appears to be true only in a limited and indirect fashion. The most consistent relationship between form and function is in terms of energy efficiency, and the more time and energy spent using an artifact the more important energy efficiency becomes. This was seen in two instances. First was the apparently universal importance of a sloping grinding surface for stones used to grind an economically significant staple. Second was the tendency for the size of the grinding surface to reflect the amount of material being processed on it. Form also appears to be related to the ability to maintain some kind of control over the substance being processed. For grinding stones this is most often seen in the presence of raised sides around the grinding surface, although the legs of the tripodal metate allow it to be placed over a collecting surface or containers.

A fifth, and even more important point concerning morphological variation is that there are many different morphological solutions to the same functional problem. This is another point which cannot be overstressed. It reinforces the previous point about the indirect relationship of form and function as well as having adaptive implications as mentioned below. As an example of multiple morphological solutions, the desired slope of the grinding stone can be achieved in a number

of ways. It may be propped up on pebbles, built into a permanent bin, or made with legs of different heights. Similarly, there are many ways to achieve control of the ground product.

A sixth point, corollary to the above, is that socioeconomic context is as important as function in determining form. The available technology once again is a critical factor in that it determines the possible range of morphological variation available. As well, social tradition seems to have an influence on form within the limits allowed by functional and technological constraints. Here again the legs on Mesoamerican metates provide an example. Their desirability may be at least partially attributed to some sense of social "prestige", but their present widespread occurrence seems to have been facilitated by the introduction of steel tools. The influence of tradition may also be seen in the variation in shape of the grinding surface of metates between San Mateo and Aguacatenango, but again within the size limitations imposed by function.

A seventh point concerns the present inadequacy of distributional data to provide functional and social information. The reasons resulting in the spatial location and frequency of grinding stones (and most likely other artifacts) in the cultural context are not well known and appear to vary with the context itself. Family structure may sometimes be associated with the number of grinding stones per household although this will vary depending on the underlying processes of

family organization as well as on the extent of village incorporation in a regional economy. The problems associated with interpreting this sort of variation in the material inventory are compounded when the cultural context is transformed to an archaeological context, particularly since the transformation process itself seems to vary with the cultural context.

Finally, the point needs to be made that no matter how traditional modern-day Mesoamerican villages may appear acculturation is occurring, and is affecting the material inventory. One of the results is a reduction of the variation in grinding stone technology and function. Thus, to repeat the initial point, the variation and patterning in grinding function and technology that might be expected in an archaeological assemblage is probably much greater than most current ethnographic observations would suggest.

Adaptive Behavior

Earlier it was stated that, following the assumptions of design theory, analysis of grinding stones (or other artifacts) should provide some insight into the nature of the adaptive problem being solved. The argument was that conflict would occur between the constraints on artifact design. As a result of selection between constraints in the design process the artifact would show some apparent diseconomies. These apparent diseconomies would be balanced by other economies of greater relevance to the adaptive problems of greatest concern to the

users. Throughout the analysis of grinding stones a number of conflicts have been noted. In particular, a conflict between functional and technological constraints occurred in both material selection and in the form of the tripodal metate. In Mesoamerica the preference for igneous materials, especially vesicular basalt, reflects the importance of maize in the diet in general. More particularly, however, it is almost certainly related to the practice of cooking maize prior to grinding. On the other hand, the present day preference for the tripodal form probably reflects a variety of social influences, including a long term association of the tripodal form with social prestige. In both these instances the resolution of the conflict was dependent on the modification of the technological constraints, in part by the presence of craft specialization.

Craft specialization, with its alteration of technological constraints, appears repeatedly as an important means of resolving conflicts between various constraints. In addition, it represents a shift in socioeconomic organization, and a major step in the evolution of technology. As such, it has been the subject of considerable theoretical interest. One of the explanations that has been suggested as a critical factor in the development of trade and, either explicitly or implicitly, of craft specialization is differential access to scarce, localized resources such as vesicular basalt (Rathje 1972:386-387; Arnold 1980:147). However, the scarcity of resources does not automatically make them desirable, or create a demand. Their

scarcity is irrelevant unless there is such a pre-existing demand. Another explanation that has been presented for the development of craft specialization is the existence of an inadequate subsistence base (Arnold 1980: 147, 150). In reality, however, this explanation is usually based on situations where the subsistence base is not inadequate so much as unequally distributed, with the result that it is inadequate only for some individuals. These individuals may turn to craft specialization as a means of increasing their income and thereby improving their subsistence but only in the context of an already established specialization. For an individual to originate a specialized production activity as a source of income where there is no known demand for the product would be to exchange a known marginal existence for an unknown and almost certainly disastrous risk. Furthermore, there would have to be a regional or local subsistence surplus--or at least sufficiency--to allow the redistribution necessary to compensate the specialist.

Neither of the above theories concerning origins of craft specialization takes into account the source of the product demand or the means of compensation for the specialist. The analysis of San Mateo grinding stones suggests one possible model for the origins of craft specialization which takes into account the source of demand, and which could be combined with one or both of the above explanations. As maize became increasingly important in the diet, the functional advantages of

using vesicular basalt or other igneous materials would also increase. The functional desirability of vesicular basalt would increase even more with the practice of precooking maize. In fact, the igneous materials may even be necessary, in which case there would be an extremely high demand. At the same time both the difficulty of working the stone and its localized distribution would make it extremely costly. Within this context the potential for the extended family to provide the basis for a low order of behavior specialization could also be quite important. Where some minimal specialization occurred in a domestic context, an increased and continuing demand would provide positive reinforcement for continued development of craft specialization.

Specialization in the production of metates appears to be the rule throughout the ethnographic Maya area and much of Mesoamerica (McBride 1947; Aschmann 1949; Wisdom 1940). The Malacatancito quarry site, which obviously has a long history of use, and the nearby archaeological site of Pukal, which may date from the Formative (personal observation; Hayden:pers. comm.), both suggest that specialization in metate production has its origins deep in the past. This is further suggested by the appearance of the specialized small footed grinding stones in the Formative. Once craft specialization occurs the entire social context has changed. Technological constraints on morphology have been altered, and, presumably, new socially generated adaptive problems must be solved.

Another major conflict in constraints was seen in the choice of modern industrial replacements used to supplement the metate. It was seen, first of all, that the metal corngrinder was the superior choice only in terms of monetary benefit and that the motor-driven mill was in fact preferable in terms of time, energy, and dependability. It was further suggested that the preference for metal corngrinders probably reflected a greater involvement in activities and/or relationships where a concern for monetary values was adaptive. Thus, the major difference between San Mateo and Aguacatenango with respect to modern grinding technology was attributed to the greater involvement of Aguacatenango residents in the modern economy, and subsequently increased acculturation. On the other hand, San Mateo was interpreted as continuing to remain more traditional partly as a consequence of greater isolation from modern society and increased self-dependence for subsistence. The emphasis on artifact dependability, both in terms of extended use-life and minimization of time and energy required for artifact maintenance was also suggested as a partial explanation for the apparent diseconomy of importing grinding stones of locally non-available material.

Future Considerations

On the basis of the present analysis of ethnographic grinding stones a number of recommendations can be made. First, grinding stones deserve much more attention than they presently receive. When variation in material, size, and shape are taken

into account they can provide a surprising amount of information. Archaeological grinding stones have the potential for increasing our understanding of subsistence behavior, the relative importance of different subsistence resources, the social implications of special use artifacts, and possibly even some of the mechanisms underlying cultural change and evolution. Second, material analyses should be given a much greater role in archaeological interpretation, particularly given the close relationship between material and function. The importance of material analyses should be even more apparent given the multiple sources of constraint on artifact morphology and the variation in morphological solutions to those problems. Finally, design theory deserves more extensive use in studies of material culture from both ethnographic and archaeological sources. Because design theory relates the alternative decisions that must be made in the selection of material and production of artifacts to the adaptive problems being solved it has the potential for unifying multiple levels of analysis and interpretation. Furthermore, it provides a solid basis for increasing our understanding of the relationships between the material objects of culture and the cultural contexts in which they occur.

REFERENCES CITED

- Alexander, Christopher
 1974 Notes On The Synthesis Of Form. Harvard University Press, Cambridge.
- Arnold, Dean E.
 1980 Localized Exchange: An Ethnoarchaeological Perspective. In Models and Methods in Regional Exchange, edited by Robert E. Fry. Society for American Archaeology Papers No. 1: 147-150.
- Aschmann, Homer
 1949 A Metate Maker of Baja, California. American Anthropologist. 51:682-686.
- Bartlett, Katharine
 1933 Pueblo Milling Stones of the Flagstaff Region and Their Relation to Others in the Southwest: A Study in Progressive Efficiency. Museum Of Northern Arizona Bulletin 3.
- Borhegyi, Stephan F. de
 1965 Archaeological Synthesis of the Guatemalan Highlands. In Vol. 2, Archaeology of Southern Mesoamerica, Part I, edited by Gordon R. Willey, pp. 3-58. In Handbook of Middle American Indians, edited by Robert Wauchope. University of Texas Press, Austin.
- Brady, George S.
 1971 Materials Handbook (tenth ed.). McGraw-Hill, New York.
- Brooks, Robert L.
 1982 Events in the Archaeological Context and Archaeological Explanation. Current Anthropology 23:67-75.
- Clark, John L.
 1980 Chapter V. Ground Stone. Ms. on file, New World Archaeological Foundation, San Cristobal de las Casas, Chiapas, Mexico.
 Pers. Comm. University of Michigan, Ann Arbor.
- Coe, William R.
 1965 Artifacts of the Maya Lowlands. In Vol. 3, Archaeology of Southern Mesoamerica, Part II, edited by Gordon R. Willey, pp. 594-602. Handbook of Middle American Indians, edited by Robert Wauchope. University of Texas Press, Austin.

- 1959 Piedras Negras Archaeology: Artifacts, Caches and Burials. Museum Monographs. The University Museum, University of Pennsylvania, Philadelphia.
- Colson, Elizabeth
1979 In Good Years and in Bad: Food Strategies of Self-Reliant Societies. Journal of Anthropological Research 35:18-29.
- Cook, Scott
1981 Zapotec Stoneworkers: The Dynamics of Rural Simple Commodity Production in Modern Mexican Capitalism. Ms. on file, Department of Anthropology, University of Connecticut.

1973 Stone Tools for Steel-Age Mexicans? Aspects of Production in a Zapotec Stoneworking Industry. American Anthropologist 75:1485-1503.

1970 Price and Output Variability in a Peasant-Artisan Stoneworking Industry in Oaxaca, Mexico: An Analytical Essay in Economic Anthropology. American Anthropologist 72:776-801.
- Damon, Albert, Howard W. Stoudt and Ross A. McFarland
1966 The Human Body in Equipment Design. Harvard University Press, Cambridge.
- Deal, Michael
Pers. Comm. Simon Fraser University, Burnaby, B.C.
- Duby, Gertrude, and Frans Blom
1969 The Lacandon. In Vol. 7, Ethnology, edited by Evon Z. Vogt, pp. 276-297. In Handbook of Middle American Indians, edited by Robert Wauchope. University of Texas Press, Austin.
- Eggan, Fred
1950 Social Organization of the Western Pueblos. University of Chicago Press, Chicago.
- Flannery, Kent V., and Marcus C. Winter
1976 Analyzing Household Activities. In The Early Mesoamerican Village, edited by Kent V. Flannery, pp. 34-47. Academic Press, New York.
- Goodyear, Albert C. III
1975 Hecla II and III An Interpretive Study of Archaeological Remains From the Lakeshore Project, Papago Reservation, South Central Arizona. Arizona State University Anthropological Research Paper No. 9.

- Gould, R. A.
1980 Living Archaeology. Cambridge University Press,
Cambridge.
- Hammond, Norman
1975 Lubaantun: A Classic Maya Realm. Peabody Museum
Monographs, No. 2.
- Hayden, Brian
Pers. Comm. Simon Fraser University, Burnaby, B.C.
- Hill, Percy H.
1970 The Science of Engineering Design. Holt, Rinehart and
Winston, New York.
- Jones, J. Christopher
1970 Design Methods: Seeds of Human Futures. John Wiley &
Sons, New York.
- Kidder, A. V.
1947 The Artifacts of Uaxactun, Guatemala. Carnegie
Institution of Washington, Publication 576.
- Kidder, Alfred V., Jesse D. Jennings and Edwin M. Shook
1946 Excavations at Kaminaljuyu, Guatemala. Carnegie
Institution of Washington, Publication 561.
- Kleindienst, Maxine R.
1975 Comment. Current Anthropology 16:382-383.
- Kraybill, Nancy
1977 Pre-Agricultural Tools for the Preparation of Foods in
The Old World. In Origins of Agriculture, edited by
Charles A. Reed, pp. 485-521. Mouton, The Hague.
- Lange, Frederick W. and Charles R. Rydberg
1972 Abandonment and Post-Abandonment Behavior at at Rural
Central American House-site. American Antiquity
37:419-432.
- Laughlin, Robert M.
1969 The Tzotzil. In Vol. 7, Ethnology, edited by Evan Z.
Vogt, pp. 152-194. In Handbook of Middle American Indians,
edited by Robert Wauchope. University of Texas Press,
Austin.
- Leung, Felicity
1981 Grist and Flour Mills in Ontario: From Millstones to
Rollers, 1780s-1880s. History and Archaeology 53. Parks
Canada, Ottawa.

- Longyear, John M. III
1952 Copan Ceramics, A Study of Southeastern Maya Pottery.
Carnegie Institution of Washington, Publication 597.
- MacNeish, Richard S., Antoinette Nelken-Terner, and Irmgard W. Johnson
1967 The Prehistory of the Tehuacan Valley, Vol. 2: Nonceramic Artifacts. University of Texas Press, Austin.
- Martin, Paul S.
1972 Conjectures Concerning the Social Organization of the Mogollon Indians. In Contemporary Archaeology, edited by Mark P. Leone, pp. 52-61. Southern Illinois University Press, Carbondale.
- McBryde, Felix Webster
1947 Cultural and Historical Geography of Southwest Guatemala. Greenwood Press, Westport, Connecticut.
- Mindeleff, Victor
1891 A Study of Pueblo Architecture. Annual Report of the Bureau of Ethnology, No. 8. Washington, D. C.
- Moritz, L. A.
1958 Grain Mills and Flour in Classical Antiquity. Clarendon Press, Oxford.
- Murphy, Glenn
1957 Properties of Engineering Materials. International Textbook Company, Pennsylvania.
- Nash, Manning
1969 Guatemalan Highlands. In Vol. 7, Ethnology, edited by Evon Z. Vogt, pp. 30-45. In Handbook of Middle American Indians, edited by Robert Wauchope. University of Texas Press, Austin.
- Nelson, Ben A.
1981 Ethnoarchaeology and Paleodemography: A Test of Turner and Lofgren's Hypothesis. Journal of Anthropological Research 37: 107-129.
- Pozas, Ricardo
1959 Chamula Un Pueblo Indio de Los Altos de Chiapas.
Memorias del Instituto Nacional Indigenista Vol. VIII.
- Proskouriakoff, Tatiana
1962 The Artifacts of Mayapan. In Mayapan, Yucatan, Mexico, by H. E. D. Pollock, Ralph L. Roys, T. Proskouriakoff and A. Ledyard Smith. Carnegie Institution of Washington, Publication 619:321-501.

- Pye, David
1968 The Nature and Art of Workmanship. Cambridge University Press, Cambridge.
- 1964 The Nature of Design. Studio Vista, London.
- Bathje, William L.
1972 Praise the Gods and Pass the Metates: A Hypothesis of Development of Lowland Rainforest Civilizations in Mesoamerica. In Contemporary Archaeology, edited by Mark P. Leone, pp. 365-392. Southern Illinois University Press, Carbondale.
- Redfield, Robert, and Alfonso Villa Rojas
1962 Chankom, A Maya Village (abridged ed.). University of Chicago Press, Chicago.
- Rich, Jack C.
1947 The Materials and Methods of Sculpture. Oxford University Press, New York.
- Rogers, Everett M. and F. Floyd Shoemaker
1971 Communication of Innovations. The Free Press, New York.
- Rosenthal, Daniel and Robert M. Asimow
1971 Introduction to the Properties of Materials (second ed.). Van Nostrand Reinhold Company, New York.
- Roys, Ralph L., translator and editor
1965 Ritual of the Bacabs. University of Oklahoma Press, Norman
- Runnels, Curtis N.
1981a A Diachronic Study and Economic Analysis of Millstones From the Argolid, Greece. Unpublished Ph. D. dissertation, Indiana University. University Microfilms International, Ann Arbor, No. 8119022.
- 1981b Millstone Analysis in Lithic Studies and Economic Archaeology. Paper presented at the Forty-sixth Annual Meeting of the Society for American Archaeology, San Francisco.
- Russel, Frank
1908 The Pima Indians. In Twenty-sixth Annual Report (1904-1905), pp. 3-390. Bureau of American Ethnology, Smithsonian Institution, Washington, D.C.
- Schiffer, Michael B.
1972 Archaeological Context and Systemic Context. American Antiquity 37:156-165.

- Scholes, Francis V. and Ralph L. Roys
 1968 The Maya Chontal Indians of Acalan-Tixchel. University of Oklahoma Press, Norman.
- Shook, Edwin M.
 1965 Archaeological Survey of the Pacific Coast of Guatemala. In Vol. 2, Archaeology of Southern Mesoamerica, Part I, edited by Gordon R. Willey, pp. 180-194. In Handbook of Middle American Indians, edited by Robert Wauchope. University of Texas Press, Austin.
- Soustelle, Jacques
 1937 La Culture Materielle de Indiens Lacandones. Journal de la Societe des Americanistes N.S. 29:1-95.
- Starr, Martin Kenneth
 1963 Product Design and Decision Theory. Prentice-Hall, Englewood Cliffs, N.J.
- Storck, J. and W. D. Teague
 1952 Flour For Man's Bread: A History of Milling. University of Minnesota Press, Minneapolis.
- Stromsvik, Gustav
 1937 Notes on Metates from Calakmul, Campeche, and From the Mercado, Chichen Itza, Yucatan. Carnegie Institution of Washington, Contributions to American Archaeology 3(16): 123-127.
- 1931 Notes on the Metates of Chichen Itza, Yucatan. In Carnegie Institution of Washington Contributions to American Anthropology and History 4:141-157.
- Tax, Sol and Robert Hinshaw
 1965 The Maya of the Midwestern Highlands. In Vol. 7, Ethnology, edited by Evon Z. Vogt, pp. 69-100. Handbook of Middle American Indians, edited by Robert Wauchope. University of Texas Press.
- Thompson, J. Eric
 1939 Excavations at San Jose, British Honduras. Carnegie Institution of Washington, Publication 506.
- Tourtellot, Gair
 1970 The Peripheries of Seibal: An Interim Report. In Monographs and Papers in Maya Archaeology, edited by William R. Bullard, Jr., pp. 405-420. Papers of the Peabody Museum of Archaeology and Ethnology, Volume 61.

Villa Rojas, Alfonso

1969a Maya Lowlands: The Chontol, Chol, and Kekchi. In Vol. 7, Ethnology, edited by Evon Z. Vogt, pp. 230-243. In Handbook of Middle American Indians, edited by Robert Wauchope. University of Texas Press, Austin.

1969b The Tzeltal. In Vol. 7, Ethnology, edited by Evon Z. Vogt, pp. 195-225. In Handbook of Middle American Indians, edited by Robert Wauchope. University of Texas Press, Austin.

Vogt, Evon Z.

1969 Zinacatan: A Maya Community in the Highlands of Chiapas. The Belknap Press of Harvard University Press, Cambridge, Massachusetts.

Wagley, Charles

1941 Economics of a Guatemalan Village. Memoirs of the American Anthropological Association, No. 58.

Weaver, Muriel Porter

1972 The Aztecs, Maya, and Their Predecessors. Seminar Press, New York.

White, Lynn, Jr.

1962 Medieval Technology and Social Change. Oxford University Press, London.

Willey, Gordon R., William R. Bullard, Jr., John B. Glass, and James C. Gifford

1965 Prehistoric Maya Settlements in the Belize Valley. Papers of the Peabody Museum of Archaeology and Ethnology, Harvard University, Vol. 54.

Winship, George Parker

1896 The Coronado Expedition, 1527-1547. Annual Report of the Bureau of Ethnology, No. 14. Washington, D. C.

Wisdom, Charles

1940 The Chorti Indians of Guatemala. University of Chicago Press, Chicago.

Woodbury, Richard B. and Aubrey S. Trik

1953 The Ruins of Zaculeu. United Fruit Company, Boston.