PHYSICAL PRINCIPLES IN STONE WORKING:
SOME ASPECTS OF ECUADORIAN CHIPPED STONE TECHNOLOGY

by

William H. G. Morgan

An Abstract

ABSTRACT

This thesis is primarily concerned with the principles of transmission of applied force in solid materials, with particular interest in applying these principles to stone chipping technology in order to correlate specific results of particular techniques of manufacture with the underlying principles of physics producing these formal results. To implement this above concern, a general discussion is presented of the physical principles of force transmission in different media, with particular reference to the natural glass, obsidian, and to synthetic glass which possesses duplicate physical properties to a very great degree.

It is concluded that fracture of lithic materials such as obsidian and flint is caused by the transmission of applied force by means of shear waves and crack propagation. Shear waves result in shear stress and strain which eventually result in plastic flow along the surfaces of maximum

stress and ultimately in fracture or rupture of the material.

A section on general aspects of Old and New World chipped stone technology is followed by a portion of the text devoted to the presentation of specific formal traits or attributes of stone artifacts noted by experimenters in stone working as resulting from specific techniques of manufacture previously described under general stone technology.

A portion (those artifacts termed "blade-like flakes") of the El Inga, Ecuador collection of obsidian artifacts held in the Laboratory of Anthropology, University of Manitoba, is analysed in terms of a number of attributes previously described as relatable to particular manufacturing techniques. These particular attributes have been selected because they are known, by inspection, to be present among artifacts in the El Inga collection. Statistical techniques are employed to facilitate interpretation of the frequencies of these attributes and of their various combinations in the collection sample of blade-like flakes as indicative of the presence here of a preferred technique of blade manufacture.

Finally, similar kinds of problems, entailing the investigation and interpretation of different attribute combinations than those handled in this thesis, are posed for future studies of the El Inga collection.

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PREFACE

It is my feeling that a knowledge of the principles and processes of physics underlying all techniques of stone technology is an absolute prerequisite for a clear understanding of the nature of formal attributes possessed by artifacts resulting from such technology. Physical principles involved in the application of force to stone materials and the subsequent fracture of these materials ought to be closely examined to provide a background for the subsequent empirical correlation of specific formal attributes and specific techniques of manufacture. I am not presently aware of the existence, in archeological literature, of such a study and I feel that this paper may constitute a real contribution to the direction of further research in this line.

I have worked in this thesis with selected portions of a collection of obsidian artifacts from the Ecuadorian Highlands in attempting an analysis of specific attributes and their correlation with specific manufacturing techniques. Such observations as I have made in this respect are based upon results noted by a number of experimenters in stone working and upon published results of fracture experiments in the glass industry.

I wish to acknowledge my indebtedness to Dr. W. J. Mayer-Oakes for his very substantial assistance in planning the research embodied in this thesis. Further acknowledgements are due to my wife, Donna, for her aid in the preparation of thesis illustrations and to my mother, for her repeated efforts in the typing of this manuscript.

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INTRODUCTION

In examining a collection of stone artifacts, even the casual observer will note that there are a number of traits or characteristics of form which recur in many or most artifacts viewed. Many of these characteristics, such as colour and texture, are dependent upon the raw material from which the artifact was manufactured. Other recurring traits do not seem to owe their presence merely to the nature of raw material employed, but rather appear to be the visible result of the particular processes of modification as an artifact to which this raw material has been subjected.

When raw stone material is being modified as an artifact, the manufacturer makes use of physical principles of transmission of force in solid media. I do not, of course, mean to imply that a manufacturer usually possesses any kind of exact knowledge of the theoretical nature of force transmission in solids. Rather, he has learned experimentally, or through having been taught, that if he strikes a certain kind of chunk of raw material at a certain angle, with a certain force and with a certain kind of striker, he may be able to control to a high degree the overall shape of the chip struck off the chunk of material.

In archeological literature, there is a considerable number of publications where note has been made of specific formal traits or characteristics of artifacts which have been seen in experiment to result from certain ways of working stone material. It is often possible to say that a specific characteristic of a particular stone artifact is the result of a specific technique employed in its manufacture. Little or no attempt is made in these publications to explain, in terms of physical principles of force transmission, why a specific trait (and not certain others) should result from a specific manufacturing technique. I shall attempt in this thesis to compile lists of traits which have been seen empirically to be associated with specific techniques, and to explain this association in terms of physical principles of force transmission to be outlined prior to the compilation of the trait lists.

Next, I shall handle a collection of obsidian artifacts from El Inga, Ecuador, examining the collection for specific traits (or attributes, as I shall later use the term) chosen on the basis of the above mentioned trait lists for their technological significance. In other words, I shall work with specific traits which have been empirically demonstrated to result from specific manufacturing techniques. It is thought that a statistical handling of the frequency of combinations of these traits will be helpful in determining whether or not the collection exhibits any preferred technique of manufacture.

During previous years of graduate work in archeology at the University of Manitoba, a feeling had arisen, among students and staff alike, that a need existed for some kind of fixed model for the systematic organization of archeological research. By the end of the 1966 academic year, this need had been met by the staff and student members of a graduate seminar in archeology (Mayer-Oakes 1966a), culminating in a research model labelled "The Ideal Model For the Total Archeological Process".

I intend to structure the research comprising this thesis in accordance with the model, but do not wish to create the impression that it is merely a device for the organization of the writing of archeological papers or reports. Rather, the model might best be viewed as a way of thinking about and planning research strategy upon any archeological problem, from the most specific and concrete to the most general and abstract.

Although the reader is referred to the above cited paper by Mayer-Oakes for detail on the research model, a brief description is in order here. The model consists of four sequential <u>operations</u>, each of which is a category of kinds of established archeological activities and none of which has a set specific content. That is, though the content of an operation be conceived, generically, as of one "kind", the specific content will depend upon the particular problem to which the model is applied at any one time.

Each operation is characterized by a major research objective, this term referring to the goal or aim of a particular segment of research. The four sequential operations and their identifying kinds of major objectives, here looking at the model in the most general way, are as follows:

1) Problem Formulation

The major objective here is the verbalization of the problem which an archeologist has sensed in data somewhere encountered, and the further statement of a testable hypothesis purporting to account for the data as observed.

2) Observation

Here the major objective is the gathering of data which the archeologist deems relevant to the testing of the above hypothesis.

3) Description

The major objective here being the description of data collected in the course of the previous operation. Each archeologist will choose whatever analytic or classifactory devices he believes fitting to his problem in order to describe the data.

4) Interpretation

Here the archeologist must interpret his described data in terms of the hypothesis put forth in the first operation.

It is clear, then, that any particular archeological activity will be included in that operation whose major objective it most immediately serves.

Major objectives of operations are to be achieved, in each case, by a method, which may be seen as the posing of a series of minor objectives, each of which may or may not depend upon the accomplishment of the prior objective for its completion. The term technique, as employed in the model, refers to the manner of mechanical performance required to achieve a minor objective.

The four operations are necessarily sequential then, as each depends upon the one preceding for its existence. Possibly of equal importance is the fact that the operations of the model are systematic, in that changes occurring in one will effect changes in at least one other, even one prior in time of initial accomplishment. There is, then, a kind of dynamic feedback process built in to this research model.

Finally, the model has two different kinds of possible application in archeology: (1) as a means of effectively organizing research strategy bearing upon a specific archeological problem, and (2) as a means of systematically bringing together the total range of established archeological activities at whatever level of generality or specificity. As regards this thesis, it is clearly in the former capacity that the model will function.

CHAPTER I

OPERATION 1 - PROBLEM FORMULATION

Major Objective

To begin any kind of archeological research, one must take the concept <u>artifact</u> as a given, conceived broadly as an object whose natural state has been intentionally modified by human agency. It has been made admirably clear in recent archeological literature that artifacts ought to be viewed as possessing properties peculiar to each of the three discrete dimensions - form, space and time (Spaulding 1960: 438). Further, artifact function has been viewed in a way making function analagous to a fourth dimension (Binford 1962). This thesis will deal, in the main, with the formal dimension of artifacts.

An artifact <u>attribute</u> may be here defined, in a preliminary way only, as a trait or characteristic of any dimension of that artifact. Formal attributes or artifacts may be related to either the natural state of the material constituting the artifact, or to the process of modification of the material by human agency. These attributes will sometimes be visible to the naked eye, but many formal attributes are seen clearly only with the aid of a microscope.

Processes of intentional modification of natural material by human agency are what I shall refer to as techniques of artifact manufacture. In order to relate specific, deliberate manufacturing techniques to resultant formal attributes, one must have at least a general knowledge of the physical laws governing the transmission of applied force throughout the solid media representing the raw materials of artifact manufacture. One American archeologist, who has taken considerable interest in the mechanics of certain aspects of lithic artifact manufacture, has indicated his concern with the ignorance, on the part of his colleagues, of the basic principles involved in such technology (Witthoft n.d.: 2). Witthoft is referring here specifically to the nature of raw materials and to differences in techniques of manufacture of stone artifacts. It seems safe to assume that an at least equally unclear state of knowledge exists among American archeologists with respect to physical laws governing the internal transmission of forces applied externally to natural materials in the course of various techniques of manufacture.

Hypothesis I. - The statement of Hypothesis I is the major objective to be formulated in this operation. It is the proposition that specific formal attributes of stone artifacts may be interpreted as the result of specific manufacturing techniques, given a background of empirically observed correlations between specific attributes and specific techniques. Those background data are to be drawn from published accounts of relevant practical experiments in stone technology. Further, I theorize in the above connection that observed specific correlations of manufacturing technique and artifact attribute may be interpreted as resulting from the action of specific physical principles of force transmission in stone materials. In this regard, a general discussion of physical principles of force transmission in solids and of the physical properties of solid media (especially stone) will be necessary.

Minor Objective

Subsequent to the testing of Hypothesis I, I intend to test a second and related hypothesis, namely, that statistically observed frequencies of certain formal attributes of those obsidian artifacts termed blades, contained in an artifact assemblage from El Inga, Ecuador (Mayer-Oakes 1965) may be interpreted as resulting from preferred or avoided techniques of manufacture. The means of testing this hypothesis (other than the achievement of the testing of Hypothesis I as above) are partially contained in minor objectives 4, 5 and 6 of Operation 2 to come. Finally, in testing this second hypothesis, statistical techniques will be applied to observed frequencies of specific attributes and their combinations in order to determine the significance of the difference between observed and expected frequencies in the collection. Subsequently, frequencies of these specific formal attributes and their combinations will be interpreted, where such interpretation is thought to be statistically valid, as reflections of preference or avoidance of specific manufacturing techniques. By this I mean that a particular combination of attributes appearing with a frequency much higher than that which would statistically be expected from chance alone, and where the technological significance of each attribute has been previously demonstrated, ought to be amenable to interpretation as the presence of a particular preferred technique of manufacture.

CHAPTER II

OPERATION 2 - OBSERVATION

Major Objective

In this operation I shall attempt to assemble a body of data relevant to and sufficient for the testing of the hypotheses promulgated in Operation 1.

Method

The method of accomplishing this major objective is viewed as comprising the accomplishment of six sequential minor objectives:

1) A discussion of the physical principles involved in the distribution of applied force in solid media.

2) Preparation of a general statement on stone technology and materials as known from Old and New World prehistory, emphasizing the blade as a concept.

3) A tally of observations made by experimenters in stone technology, on correlations between specific techniques and certain formal attributes of artifacts produced; and presented in terms of physical principles.

4) A description of the material to be handled

from the El Inga site, conducted in the light of the above three objectives.

5) By comparison of recent archeological literature, the derivation of a general statement on conceptual archeological theory pertinent to this thesis.

6) The presentation of a specific conceptual framework for the analysis and recording of formal attributes of artifacts to be handled from the El Inga collection.

Distribution of Force in Solids (Minor Objective 1)

Solids. - Matter is considered to be in the solid state when it will return to its original form when applied force has been removed. There is no sharp boundary between the ideal solid and the ideal liquid. One must resort to a description of differences in molecular structure and cohesiveness when dealing with a substance of constant chemical composition, but which may exist as a gas, liquid or solid.

Force. - In physics, a force is defined minimally as a push or pull on an object. In the measurement of a force, both magnitude and direction must be specified. The point at which a force is applied must be stated in the delimitation of force direction. A complete description of a force would read something like "a man exerts at the point O a force of fifty pounds in the direction of OA" (Heil and Bennett 1939:3). Forces may thus be treated as vector quantities and any one force may be resolved into component forces acting in different directions (Fig. 1a). In this figure, C1 and C2 are vectors of two component forces into which force F may be resolved. Force here is treated as acting upon a particle or point, some indefinitely small portion of an object (Hills 1963:80).

Wave Motion. - When a solid is struck at any point, a compressive energy moves through the solid at a uniform velocity in a series of pulses (Heil and Bennett 1939:272). Although the initial force application is but one single pulse, the elastic properties of the body cause an action and reaction between adjacent molecules, a kind of back and forth motion of particles which causes the initial pulse to be sent out as a series of pulses, dying out the further distant from the original source. The velocity of this pulse transmission depends upon the medium in which it is transmitted (Heil and Bennett 1939:289-291). A more rigid and highly elastic medium such as steel would transmit a given initial pulse more rapidly than, say, wood. Only energy is transmitted by pulse action, not matter. Where the transfer of energy is at right angles to the motion of particles in the compressional pulse, a <u>transverse</u> wave results. A <u>longitudinal</u> wave results when energy transfer is in the same direction as the motion of the particles in the pulse (Fig. 1d). In the transverse wave depicted in this figure, the transfer of energy is from left to right (as indicated by the arrow), while the actual motion of particles is at a right angle to the direction indicated by the arrow. An analogy here is the way in which a pulse travels along a rope secured at one end and moved up and down in a vertical plane at the other end. An analogy for the longitudinal wave is a series of golf balls suspended by strings in a straight line and in one horizontal plane, and touching one another. When a force is applied to the ball at one end of the line a pulse travels along the line of balls to the ball at the far end which will move for a time in the direction of the initial force, but will eventually (because of gravity in this example) stop and reverse direction, striking the line of balls and setting up a pulse in the opposite direction from that of the initial pulse. Such analogies ought not to be overworked, but may be helpful.

Both kinds of waves will be dealt with later in the text in the context of their respective roles in the process of fracture of solid materials.

With reference to transverse waves, two waves in the same wave plane, but coming from two different sources, will cancel each other out if the peak of one interferes with the trough of the other (Fig. 1d). Conversely, if two wave peaks coincide, they reinforce each other and result in a larger peak.

Both longitudinal and transverse waves propagated in an elastic solid will be reflected back from the boundaries of the body (Morse 1958: 3-101). Transverse waves may be reflected as longitudinal waves and longitudinal as transverse. Clearly, the interaction of wave fronts in a body will become a very complex network, relative to the particular molecular structure and shape of the body.

There is a kind of transverse wave which is propagated at a tangent to the direction of motion of particles in a pulse, this being termed a shear wave. Actually, when a force is applied to an elastic body, a large number of shear waves radiate out in all directions from the point of contact. There is an obvious relationship between the transfer of energy by shear waves and the shear stresses and strains dealt with below under appropriate headings. In shear waves, the pulse "proceeds outwards along ever-expanding cylindrical surfaces" (Heil and Bennett 1939: 282).

When a vertical force is applied to a plane surface on an elastic body, a transverse circular wave or pulse passes out along the surface with the point of contact as centre (Fig.1e). Such a surface disturbance also produces a hemispherical wave within the elastic body. A spherical wave is produced in such a body when a disturbance is effected at a point within it.

The distance between the peaks of waves along a transverse wave plane is termed the wave length, and wave length relates to the velocity of the initial pulse or force application, so that one may state that the higher the velocity of force application, the shorter the wave length. Magnitude of the initial pulse will determine the strength of the wave front, or how far it will propagate into a given elastic body, but does not relate to wave length.

Stress. - Internal forces are set up in a body by the application to it of an external force or forces. The resultant internal action and reaction of adjacent particles in the body (the state of stress) is not amenable to analysis by the use of force vectors, but requires mathematical treatment. Stress must be considered relative to any one point in the body. A unit area or surface including this point is chosen in any direction, and stress is specified as the total of internal forces acting on this surface or unit area within the body. The plane of an arbitrarily chosen surface (Fig. 1b) will have a compressional normal stress N (right angled to the plane) and a tangential or shear stress S (of importance in later considerations) parallel to the plane. R represents the reaction to applied force F. I have noted above that many shear waves will radiate out from the point of contact in an elastic body to which external force is applied. A network of shearing stresses is therefore set up within the body. Inclined at an angle of approximately 45° to force vector F is found the maximum shearing stress (represented in generalized fashion in Figure 1b by S). This statement holds for mathematical calculations of shear stress in an idealized, infinite, elastic medium (Nadai 1931: 218). Because the state of stress within a body relates to the action and interaction of adjacent parts, the shape of the body will obviously play a great part in particular stress distributions.

<u>Strain</u>. - This concept has to do with the measure in which a body is deformed (this term means simply, in physics, put out of shape, or changed in form and is not concerned with the permanence or temporariness of this change) by stresses resulting from external force application. Although strain is viewed as caused by stress, strain propagation in a body occurs simultaneously with stress of transmission. Planes of strain will, then, correspond to stress planes.

<u>Elasticity</u>. - Principles of stress and strain have been derived from observing elastic deformations of bodies. If a strained body reverts to its original form after the removal of stress, it is said to have exhibited elasticity. A perfectly elastic solid would return

to its original shape after the removal of stress of any order of magnitude.

Plastic flow. - Materials which have a definite strain limit beyond which they will not return to original form, but yield in some measure to permanent deformation are said to exhibit plastic flow after having reached their elastic limit.

Fracture. - The eventual loss of internal molecular cohesion and the collapse of a body under stress is termed fracture or rupture of materials. The body will of course tend to fracture along one or more of the stress planes set up within it. Materials which exhibit plastic deformation before rupture are termed ductile, while those which fracture below the elastic limit are termed brittle (Lillie 1958: 8-83). Time also plays a part in the determination of the force necessary to cause rupture in materials, in that a force of a given magnitude and rate of application which does not initially cause rupture may do so after a period of time. If plastic deformation occurs continuously, eventually a body will fracture. Further, "no sudden application of high stress is necessary to produce fracture [under conditions of continuous plastic deformation]" (Griggs

1936:564). This should not be interpreted as stating that plastic flow causes fracture, rather, it tends to restrain fracture by absorbing some of the energy which would otherwise go to fracture propagation (Thomas 1961:185). The relationship here is that the high stresses which cause plastic flow may cause fracture, but both plastic flow and fracture occur independently in many cases. Figure 1c illustrates the relationship between elasticity, plasticity and fracture in ductile and brittle materials. Ductile materials are seen to undergo plastic deformation before rupture and immediately after their elastic limit has been reached. In brittle materials, however, rupture or fracture occurs immediately after the limit of elastic deformation is reached, there being no plastic flow involved. It should be noted that an extremely rapid rate of force application to normally ductile materials can produce a brittle fracture, that is, with no plastic flow. In these cases, molecular cohesion of the material is overcome by strain before plastic working has had time to develop. Short of this extreme, the general statement may be made that the more rapid the application of force, the more ductile or plastic the behaviour of the material (Griggs 1936:576).

In summary of force distribution in solids, it has been noted that when a solid medium has a force (a push of specific magnitude and direction) applied to it externally, a series of compressive energy pulses termed waves move through the medium. Internal forces thus set up cause the solid body to be in a state of stress. The measure in which the body is deformed by stress is called strain. Principles of stress and strain have both been derived by observing the elasticity of a body, its ability to revert to original form when stress is removed. Solid materials which are strained beyond their elastic limit will do one of two things. Firstly, if the medium is brittle, loss of internal molecular cohesion will result in immediate fracture. Secondly, if the material is ductile, it will yield in some measure to permanent deformation, exhibiting plastic flow. If stress and strain continue, materials undergoing plastic flow or deformation will eventually fracture.

Anisotropic Media

In anisotropic media, many physical properties vary with the particular direction in which they are observed. All materials, such as metals and most rocks, which are crystalline in structure are anisotropic. Crystals are structured in planes, and physical properties (such as elasticity and cohesive strength) of crystalline substances vary with the angle to these planes at which measurement is taken. Most rocks are heterogeneous in texture as they contain a variety of minerals in different sizes and grain shapes (Hills 1963:78). Granite and quartz are examples of crystalline, anisotropic rocks. Plastic deformation in crystalline solids takes place by deformation of one part of a crystal along crystallographic planes, termed slip-planes, formed by the original metamorphism of the rock (Hills 1963:287). Such planes are really lines of least resistance and fracture also takes place along them. Cleavage is the term used in structural geology to refer to lines of rupture formed along slip-planes in crystalline rocks. Cleavage in rock deposits is usually seen as a series of parallel lines running diagonally up the face of the rock formation. This angle is due to the fact that cleavage lines occur approximately along planes of shear stress, which (as indicated elsewhere) are found at a tangent to the direction of maximum stress (gravity, in large rock formations). Fracture, when occurring in crystallographic planes in anisotropic rocks, is termed cleavage fracture, and its direction and nature is virtually beyond human control.

Isotropic Materials

Materials of this kind exhibit the same physical properties regardless of the direction in which they are measured. The concept of isotropy is an ideal not fully realized by any material, although closely approximated by glass.

Flint, or chalcedonite. - Exists in a crystalline state where silica impurities are distributed throughout a matrix of crypto-crystalline quartz (Witthoft n.d.: 3). Although a crystalline substance, flint is composed of such tiny crystals that it behaves isotropically, not fracturing along major cleavage lines on crystal slip-planes as do rocks composed of large crystals. Quartzite also exhibits isotropic properties for the same reason as does flint.

Obsidian. - Geologically, obsidian is classified as an igneous glassy rock (Frondel 1962: 319). It is a natural silica glass formed by the rapid cooling of viscous lava with a high silica content. The chemical composition of obsidian is the same as that of granite, but rapid cooling has prevented crystallization. Bulk nodules of obsidian are found mostly in the upper portion of lava flows. Where synthetic silica glass is colorless and transparent, impurities such as iron oxide dust and crystallites of other minerals, which have been included with the molten lava, cause obsidian to be transluscent rather than transparent and to take on various color hues. Usually obsidian is black or dark grey (this is the color of the El Inga material) and this color is attributed to clusters of silica crystallites. Obsidian is slightly harder than window glass, but acts in a less brittle fashion (Bixby 1945:355). Although in a vitreous or glassy state, the chemical composition of obsidian is unstable and it undergoes a process of devitrification through time. Atmospheric water is taken in by the surface of obsidian pieces and a cortex is formed by this hydration. This process is the basis for a method of dating obsidian artifacts.

The physical properties of obsidian under applied force are obviously most important to this thesis, but I must heartily endorse the statement of the structural geologist who has recently said: "as to glassy rocks, no particular attention has been paid [in any field] to their mode of yielding or fracturing"

(Hills 1963: 78). Such observations as will be made upon the physical properties of obsidian are based upon experiments with synthetic silica glass, which exhibits physical properties nearly identical to those of obsidian. These two glasses, the one natural and the other synthetic, nearly approximate the ideal state of isotropy, although tensile forces due to cooling are present in both. The significance of these tensile forces is thought to be small in the case of bulk glass, being most observable as surface tension, causing a directional variance of, for example, strength of molecular cohesion at the surface.

Conchoidal fracture. - This kind of fracture is characteristic of isotropic bodies. In its etymology, the term conchoidal denotes shell-like, drawing attention to the homology between one half, for example, of a bi-valve clam and a fracture resulting in a chip or flake which is concave on the side attached to the main body before fracture (Fig.2a). Frequent mention is made in the literature of archeology, structural geology and engineering of the characteristic conchoidal fracture of isotropic materials, but I have yet to come across an explanation of this phenomenon. Recently

I spent two days contacting people working with solids in the Physics, Engineering and Geology Departments of the University of Manitoba, but obtained very little information about conchoidal fracture.

Figure 2b represents my own attempt to explain conchoidal fracture in logical accordance with principles of stress, strain and wave propagation previously outlined here. Experimenters in flint working have noted that force applied to a block of flint is transmitted throughout the body of the block in a particular way (Leakey 1953: 29-53). In fact, if a slab of flint is struck sharply enough in the middle with a stone hammer, a cone will be punched out the other side, much as a cone is punched out of window glass hit by a stone. This is a case of force being transmitted by shear waves (Fig. 1e) in the form of an ever-increasing cylinder, the resulting shear strain culminating in conical fracture along the line of maximum shear stress (see page 20 of this text). Figure 2b graphs the trajectories of principal shearing stresses in an elastic body, these trajectories having been recorded photographically in tests using a metal punch on a celluloid plate. I have dotted the shear trajectory line on the extreme right to designate it as the shearing stress trajectory along which a flake might be detached from a core and give the curved or parabolic cross section characteristic of a conchoidal flake. The reasons for the curving back of the shearing stress trajectories are mathematically explicable (Nadai 1931: 251) and relate to plastic working and shape of the body being tested. I am, of course, completely incompetent to deal with the mathematical procedures involved, but would like to add that Nadai's entire volume on plasticity relates to the problems which I have encountered in attempting to deal with fracture in isotropic materials. In the case of a core being struck with a hammer near one edge, not in the centre as was the celluloid plate of Figure 2b, the distribution of shearing stress trajectories would not likely be so symmetrical when graphed as it is in Figure 2b. Nevertheless, it is still possible to picture a curved shearing stress trajectory, near the core edge struck, which would result in plastic working and eventual fracture, detaching a conchoidal flake.

Glass. - I have noted under a previous heading that little if anything has been done in the way of investigating the manner of fracture of obsidian. Fortunately, a fair amount of relevant experimental work has been done on synthetic glass, the physical properties of which very closely approximate those of obsidian. Although polymerized and organic glasses do exist, the term glass as I employ it refers to inorganic glasses, which might be called the common household varieties.

Glass may be defined as: "An inorganic product of fusion which has cooled to a rigid condition without crystallizing" (Lillie 1958: 83, Part 8). Rather than being crystalline, glass is structured by bonds between atoms which form a random network of atomic structure. In this respect, glass possesses the same quality as a liquid, as it also does with regard to transparency. As previously noted, the dividing line between the ideal solid and the ideal liquid is unclear, especially in the case of isotropic media.

Glass has been traditionally considered a brittle substance, but, recently, convincing evidence has been produced of plastic flow in glass (Marsh 1964: 33-35): (1) plastic furrows and impressions may be produced on glass surfaces by a diamond point, (2) mathematical calculations of other physical properties of glass have been seen to be highly erroneous when they do <u>not</u> treat glass as a plastic substance.

In the random atomic structure of glass, some atoms <u>bridge</u> the molecules of the substance, and other similar atoms are left more or less at "loose-ends" (Marsh 1964: 41) in the structure. Plastic flow is thought to occur by displacement of these loose and non-bridging atoms. Water, either from the atmosphere or already present in the chemical composition of glass, creates more non-bridging atoms. The more water present in a glass, then, the more plastic its behaviour under force application.

<u>Fracture of Glass</u>. - The nature of <u>glass fracture</u> has received considerable attention by the synthetic glass industry. In isotropic bodies, force is transmitted internally by two kinds of waves: (1) longitudinal, (2) transverse or shear. These two are transmitted in planes which might correspond to

strain and subsequent fracture lines. As stated elsewhere, longitudinal waves seldom cause fracture, their force usually being absorbed in the bulk of the body undergoing force application. Glass fracture involves, unfortunately, more than a simple process of straight line fracture, or of conchoidal fracture, along a line of shear stress.

For some time researchers in glass industry had noticed that glass fractures under pressures which are only a fraction of those pressures calculated mathematically to be required to produce rupture. Recent publications on glass research point to the existence of microscopic and submicroscopic flaws in glass to explain this discrepancy in observed and calculated strength (Bowden and Field 1964: 335-341). In addition to these kinds of body waves mentioned above as occurring in isotropic media, there is another surface wave, the Rayleigh wave (Bowden and Field 1964: 336-337), which radiates out from a point of external force application on a glass surface. Tiny flaws on the surface already possess stress concentrations around them, and the energy of the surface pulse or wave will initiate fracture at the first flaw of sufficient size. The fracture, or fissure, begins from the surface and proceeds for some distance perpendicular to it, then changing direction to a tangent from the surface (Stanworth 1950:66-67). I would interpret this as fracture propagating along the trajectory of maximum shear stress and strain. Should fracture be initiated by pressing a spherical object upon a glass surface, a number of such cracks will be propagated (from flaws) around the circumference of the sphere and will push out a cone-shaped piece of glass if the glass is a relatively thin plate (Fig. 3a). Note that the thinner the glass body, the greater the angle of shear fracture to the direction of applied force.

A number of sources on glass research have indicated that force applied rapidly, as by a small explosion, to a glass surface causes a typical fracture (Fig. 3b) which differs from that produced by slowly applied pressure. The lines radiating from the apex of the cone in this figure are grooved lines, whose presence has not been explained by those researchers observing them (Mackenzie 1962:114-149). They are, in any event, associated with fractures caused by a rapid initial pulse. This kind of fracture is termed forked or "branching" (Mackenzie 1962:145-146). When the velocity of the crack initiating at a surface flaw reaches a maximum (the maximum being 0.6 the velocity of the shear wave) with rapidity, because of a rapid initial force application, the stress field will change and the crack will fork to follow this new distribution of stresses. Note also the distribution of fracture lines around the initial fracture crack just under the surface of the glass.

Concentric "rib" or "ripple marks" (Stanworth 1950:72-73) often appear on a glass fracture surface (Fig. 3c). Seen in cross-section, the ripple marks look like waves on water (Fig. 3d), and indeed they are the results of wave propagation and plastic flow. When the glass body is initially subjected to compressive force, whether by slow pressure or impact, a periodic transverse pulse is sent out (the shear wave). Once particles have been set in motion, the body's qualities of elastic rebound and particle interaction is enough to send out a series of pulses gradually dying out through friction. However, coupled with this is the fact that, upon rebounding elastically from the initial external pulse, the surface particles again come in contact with the object which caused this initial pulse and a new set of pulses is sent out, superimposed as it were, on the former. At times the peaks of the waves transmitting both sets of pulses will reinforce each other, causing the configuration of Figure 3d to occur where the glass has flowed plastically along the strain lines. The more rapid the application of the initial pulse or force, the more rapid the elastic oscillation of particles in the glass and therefore the higher the wave frequency. We may expect then to see more numerous and closely spaced ripple marks from a rapidly applied force than from one applied more slowly, and such is the case (Stanworth 1950:72).

Because ripple marks do not always appear on fracture surfaces, one concludes that fracture is not always preceded by plastic working along the strain line. It would appear that the maximum velocity of crack propagation in glass must be reached in order for plastic working to occur (Mackenzie 1962:141). As the shear wave velocity and crack propagation slow down towards the end of a fracture, then it would be expected that ripple marks would disappear, as plastic flow has ceased or nearly so. Such is observably the case (Stanworth 1950: 70-73).

Note has been made in the literature on glass research, that the particular form taken by glass fracture and fracture surfaces relates to the shape and composition of the object by which force is applied (Bowden and Field 1964: 331), but I have seen no details spelled out in print in this regard. It seems clear that a more rigid and elastic force applicator, such as rock, would cause pulses of higher frequency to be sent out than would a softer, less elastic material such as wood or bone, because in rebounding back against stone after being initially struck, the glass encounters a more rigid body with more rapid elastic rebound (sending out a secondary pulse) than it would if bone were the hammer.

Stone Technology (Minor Objective 2)

Bibliography. - In the course of research for this thesis, I have accumulated on file cards a list of references of general and specific publications on techniques of working stone. Many of these have been or will be cited in this text. Those references which are not to be cited, many of which I have read and a number of which I have not, will be included with pertinent cited literature in a section at the end of this text and entitled "A General Bibliography on Stone Working".

Choice of Stone Materials. - Throughout the Paleolithic in the Old World and the Lithic stage of technological development in the New World, stone technology was limited to the use of initially, percussion and, later, pressure flaking (Willey and Phillips 1958:79-103). Because of the uncontrollable fracturing of granular rock along cleavage lines, only those lithic materials of isotropic structure and, therefore, those exhibiting conchoidal fracture were suitable for the manufacture of artifacts by percussion and pressure. Obsidian and flint exhibit conchoidal fracture in a high degree, and have always been highly valued by Old and New World stone workers, often being transported over long distances from their natural sources as items of trade. Silicated fine grained minerals such as quartzite and petrified wood often fracture in an excellent conchoidal fashion and were also held in high esteem. There is no doubt that obsidian is the most controllable medium of all (Bixby 1945:355).

One might not be too far out of line to view the history of the development of stone tools in the Old World Paleolithic and the New World Lithic as the development, through transmission of technological experience from each generation to the succeeding, of man's ability to control conchoidal fracture.

Implements and Products of Stone Technology. - I am limiting discussion here, and throughout this text, to techniques of percussion and pressure flaking. Other ways of working stone, later in time in both the Old and New Worlds, are not pertinent to an analysis of the Ecuadorian artifacts with which I shall presently deal. It will be necessary here to refer to kinds of artifacts such as cores and flakes which will be dealt with in detail subsequently.

The basic tool of direct percussion, where flakes are struck off directly from a block or core, is the hammerstone. Ideal hammerstones are medium density pebbles, such as sandstone, which are smoothly waterworn and slightly pointed at one end. The round point enables the stone worker to hit a given point on the core with relative precision.

An intermediary punch is a roundly pointed column of antler or wood used in the indirect percussion technique of striking off flakes from a core. The rounded point punch is placed firmly against the face of a core, and the other end hit with a stone hammer.

The anvil or rest is a flat piece of bone, antler or wood upon which a stone object to be worked is placed for support.

A column, usually of antler or wood, used in place of a stone hammer in striking off flakes by direct percussion is termed a baton. The baton was also used by some stone workers for secondary flaking of artifacts whose shape had been previously roughed out by a stone hammer.

Used to press primary flakes off a core, the pressure flaker is a column of bone, wood or antler sharpened to a point at one end (or such a point hafted in a wood handle), the point being set near one edge of a core face and a flake pushed off by impulsive pressure. When used in secondary pressure retouching of a primary flake, the pressure flaker is a smaller version of the above, or perhaps a specially modified stone flake (Semenov 1964: 48).

Implements of percussion work such as protective leather hand pads may be inferred from ethnographic parallels as likely to have existed in the material inventory of cultures known only archeologically, but they remain solely an inference.

Primary Flake. - Such flakes are struck or pressed off a core with the intention of further modifying them by secondary percussion or pressure techniques (Bordaz 1959) for use as a specialized tool, or they might be employed just as struck off when they possess a sharp cutting edge. The term primary flake is used here to refer to flakes struck off for intended use as a tool, and does not refer to flakes struck or pressed off cores in the process of manufacturing a core tool, such as those well known in the earlier stages of the Old World Paleolithic (Bordaz 1959: 36-45). Figure 2a illustrates the general characteristics of a conchoidal flake, such as results from the fracture of flint or obsidian. The <u>bulb of force</u> is so termed, rather than bulb of percussion, because this phenomenon also results from pressure flaking.

In discussing the transmission of force in isotropic solids, it was noted that application of force to a point or particle on the surface resulted in the transmission, by periodic pulses, of particle motion in the form of a longitudinal wave parallel to the direction of propagation and a shear wave tangential to it. Of course, when force is applied to a core by a hammerstone, pressure flaker or punch, more than one surface particle is involved. From the total surface contacted by the implement, a compression wave is sent out as a partial sphere diminishing rapidly as it leaves the surface. This is the same kind of longitudinal wave as a sound wave. At the same time, a surface wave travelling across the surface of the core where force has been applied, initiates a downward crack propagation from a surface flaw (pre-existing or caused by hammer crushing) of suitable size. The crack or fracture encounters the stress line (Fig. 4a, Point a) produced by the circumference of the spherical wave, follows this circumference down and around until it encounters the trajectory of shear stress, at Point b. From this point, the fracture changes direction along shear stress and strain line bc, and plastic working may precede the tip of the fracture crack. If plastic flow does occur (depending upon the rapidity of force application), then ripple marks representing the passage of shear waves will be seen along bc, which will be conchoidal (Fig. 2b). The arc ab represents the bulb of force of the flake which will rarely if ever represent a portion of a true geometrical sphere, as the actual wave propagation in any one instance will relate to the magnitude and direction of the force vector, as well as the size, shape and density of the medium. The sequence of events presented in this paragraph comprise my own speculations on fracture in isotropic materials, and, therefore, no sources have been quoted. However, the individual events (crack propagation from surface flaws, plastic working and so on) have been attested previously in this text.

Once struck or pressed off a core, primary flakes may be subjected to secondary percussion or usually pressure flaking, either to produce a sharper edge or to modify their shape to that of a specialized tool, such as a projectile point, or a burin. When a special shape of flake is desired, the core from which it is struck or pressed off must be prepared accordingly.

The Core. - When a natural nodule or lump of stone suitable for working is available, it must be first split in order that it present a flat surface suitable for pressure or percussion flaking. The technique of splitting such nodules has been presented by several experimenters, notably L. S. B. Leakey (1953:32-34). In flint and obsidian, the cortex or outer dehydrated (or perhaps hydrated in the case of obsidian) layer must be struck off with a hammerstone. Smaller nodules may not be split, but a large flake may be struck off to expose a flat surface. This flat surface is termed the striking platform of the core, as is that portion of the surface which remains above the bulb on a detached flake. Striking platforms may be prepared, that is, roughened by abrasion or lightly flaked around the edge by percussion or pressure, in order to give the pressure flaker or intermediary punch a better purchase on the face of the core.

Most cores are modified in some way or other before flakes intended as tools are struck off. The term prepared, however, refers to a core intentionally shaped so as to yield a flake of a certain general shape and size. Prepared cores may be globular, where flakes have been detached all around in no preferred direction, or pyramidal, where the striking platform is the pyramid base, or cylindrical, with flakes sometimes detached from both ends, or hemispherical, or a combination of these shapes. All these core shapes are seen in the New World. In the Old World Paleolithic, these, plus highly specialized core shapes, are seen (Warshall n.d.: 5-8).

All cores must be somewhat rounded or contracted towards the bottom. Should a core be, for example, a straight-sided cylinder, not rounded at the bottom, the cone of force transmitted downwards from a force applied to the striking or pressure platform will be squarely opposed by another transmitted upwards by pressure of the anvil against the core bottom, and shattering of the core will be a frequent result. Short of core shatter, the overall shape of the flake detached would not be controllable.

Rounding or tapering the bottom end of a core would therefore prevent this square-on confrontation of opposed force cones, and allow the shear stress and fracture line to proceed further down the side of the core, resulting in a longer flake.

It was noted in a previous section (Fig. 3a) that shear angle in a glass body in relation to the direction of the force vector extended into the medium (as a longitudinal wave) decreases as the ratio of body thickness (length) to width increases. Therefore, the longer a core (where an isotropic medium) is in proportion to its width, the proportionately longer a flake will be detached (Fig. 4b). This statement holds for cores which are of the same general shape - cylindrical or conical, for example. The differences in the network of stress trajectories between cores of basically different shape (such as hemispherical and cylindrical) would be such that a comparison of length-width ratios would be meaningless.

Humps and hollows on the side or face of a core will affect the shape of the flake detached. The flake will widen around excess material on the core face and will constrict at depressions

(Crabtree 1966:18-19).

The Blade. - Characteristic of the Upper Paleolithic in the Old World and widely known in the New World is a special kind of core preparation and a systematic flaking technique which results in the production of a long, thin flake with roughly parallel sides, known as a prismatic blade (Fig. 5a). John Witthoft (n.d.:10) has outlined the characteristics of the blade in the following fashion:

> A blade, therefore, is a prism, or prismoid of flint [or obsidian] , of trapezoidal cross-section (sometimes triangular cross-section because the blade from each ordinary core includes a few irregular examples), fairly massive and thick, rather than sheetlike, derived from a faceted core, which may be cylindrical, oval, a truncated pyramid, or a segment of any of these forms. Rarely, a blade was used as a tool without further modification, but most of them were chipped [percussion or pressure flaked] along the edges, particularly on the dorsal or convex face, to make more specialized tools...Another important thing about blades is that they generally make up a whole industry or set of tools, being modified into several different types of tools in every complex where they are found. This is not generally true of the small derivatives which I call bladelets.....

I shall return to this concept of a bladelet in a moment, wishing to say a little more about blades first.

The advantages of this technique, blade manufacture, are many. Because blades flake off with a relatively thin section and low edge angle, they immediately present two very sharp and efficient cutting edges without secondary working (Semenov 1964:201-202). The characteristic symmetry of the blade made possible an increased use of tools where symmetry has an obvious advantage, such as projectile points and drills. Flakes produced by techniques other than prismatic blade production, were too thick to be easily modified into an efficient projectile point, being both too thick to penetrate animal hide and flesh effectively, and not carrying through the air as well as the thinner, symmetrical blade (Bordaz 1959:46). The blade was also eminently suitable for modification, by striking off a transverse flake at one end, as a burin (Fig. 5b) or chisel enabling extensive working in bone and antler not possible without this kind of tool. The manufacture of blade tools is very conservative of material, it having been estimated that a two pound flint core would yield twenty-five yards of cutting edge when worked by blade manufacture, compared to four inches of cutting edge had the core been modified by percussion as a biface of the early Paleolithic kind (Bordaz 1959:48).

Obviously, if blade tools are to be held in the hand for working, the two sharp edges will be troublesome. One edge of the blade may be blunted to overcome this problem, resulting in a backed blade, or the blade may be mounted in a wood or bone handle. Hafting the blade not only makes it more comfortable to hold, but also more efficient as a tool in that more leverage may be applied in its use. The arc seen in the longitudinal profile of a blade and which is caused by conchoidal fracture, must be worked away at both ends if the blade is to function as a tool such as a projectile point which must be symmetrical both in face view and in longitudinal cross-section.

The blade industry is seen in the New World at a time period corresponding to the latter part of the Upper Paleolithic in the Old World. What processes of diffusion might have taken place here and whether the blade industry is an independent invention in both areas are fascinating questions unanswerable in the light of present archeological knowledge. It would seem that in both the Old and New Worlds, the miniature version of the blade industry resulting in the bladelets mentioned in the above quotation by Witthoft, are later in time and developed out of the blade industry (Witthoft n.d.:11).

The term microblade is frequently used in archeological literature to denote the same concept as does bladelet. Microblade refers to a particularly diminutive form of bladelet, known best from the Northwest and Arctic regions of North America. Bladelets are something more than just a smaller version of the larger blade industry, however. As seen in the Old and New Worlds, bladelets were struck or pressed off their small faceted cores most often for use as a small knife without being modified as various types of specialized tools (Witthoft n.d.:11). This general statement does not exclude collections where bladelets are seen to be frequently retouched by pressure flaking, for purposes of hafting or producing a special kind of edge. The El Inga collection is such, as will later be more fully indicated. In North America, the two major regions of bladelet manufacture have been the Valley of Mexico and the Arctic (Swartz 1960:405). The Hopewell culture has also exhibited a bladelet industry (Witthoft n.d.:21). The difference in size and function between the blade and the bladelet is usually dealt with, by archeologists concerned, as a reflection of a relative change in available amounts of particular environmental food resources.

Obviously, the amount of technological control necessary to prepare a core and flake off a bladelet of relatively tiny proportions is very great, and a very good flint or obsidian would be a prerequisite.

In summary of this section on stone technology, I have noted that prehistoric stone technologists in the Old and New Worlds showed a marked preference for lithic materials of an isotropic nature, such as obsidian and flint, because the direction of fracture and the resultant shaping of artifacts is most controllable in these materials. The nature and purpose of the major implements of stone technology (the hammerstone, intermediary punch, anvil, baton, and pressure flaker) have been described in order that later reference in this text to techniques of direct percussion, indirect percussion and pressure flaking will be clarified. I have also dealt in a general way with artifactual results of manufacturing techniques: the primary flake, the core and the blade. Attempts were made to indicate the various forms and varieties in which these materials have been seen in the archeological record of the Old and New Worlds. These particular kinds of artifacts have been dealt with here in a general way because they are concepts central to the discussion of material handled in the analysis, later presented in this text, namely, portions of the El Inga collection.

Experimental Results (Minor Objective 3)

Enough people have experimented in the working of lithic material, particularly flint and obsidian, that a body of data is at hand sufficient for one to indicate some results, in terms of formal attributes of artifacts, that are observably correlated with specific kinds of techniques.

To begin, it is common knowledge in archeology that flint which has been exposed to weathering and lost much of its moisture content is brittle and hard to work. I have noted elsewhere (page 31 of this text) why glasses are more plastic (less brittle) the more water they hold in compound, and supposedly the same may be said for flint for homologous reasons. It has been noted that dried out lithic materials may be improved in suitability for working (but never completely recover their plastic properties) by burying them in damp earth for a period of time (Semenov 1964: 57). Actually, under at all favourable climatic conditions, obsidian tends to take on water in a surface layer of hydration, rather than dehydrating.

It is very important to note with respect to what is to follow immediately, that observations on the relationship of technique to formal attribute <u>hold constant</u> factors of core shape, size and material (unless otherwise stated) when comparisons are being made. For example, a statement such as "resolved flaking produces a straighter flake than does flat flaking", assumes that the shape and material of core are constants.

<u>Free, Flat and Resolved Flaking.</u> - John Witthoft has distinguished these three kinds of flaking, the criterion for each being the angle which the direction of applied force makes with the platform of the core, referring here to the angle on the core side and not the detached flake side of the force vector (Witthoft n.d.: 8-9). In free flaking (Fig.6a) the force vector meets the platform at an acute angle (less than 90°), while flat flaking is said

to occur when the angle is ninety degrees (Fig. 6c). In resolved flaking (Fig. 6b) the angle of force vector to core platform is obtuse, and the force is directed inwards to the core body. It must be noted here that Witthoft is dealing with flint and obsidian cores flaked by direct percussion with a stone hammer. I shall attempt to draw up a list of characteristics of flake morphology which Witthoft associates with each technique, and to explain the association between attribute and technique. Such explanations as are phrased in terms of the principles of force transmission already outlined in this text are not the responsibility of authors cited, and their defense is my responsibility alone.

According to Witthoft, in free flaking, formal attributes resulting are:

1) Wedge shaped flake, thickest at bulb end.
2) Relatively short flake.

Witthoft notes that the longitudinal section of this kind of flake is nearly the same angle as that between the force vector and the core platform (Fig. 6a). Although Witthoft makes no mention of the fact, it ought to be clear that the angle between the flake platform and the inner face of the flake will vary from that subtended by the core platform and the force vector with the absolute size and shape of the core, due to particular stress trajectories occasioned by each.

Attributes seen by Witthoft to result from <u>resolved</u> flaking are:

1) Cross section with bulb end narrower than distal end of flake.

2) Large (prominent) bulb of force.

3) Flake is relatively straight rather than arched or curved.

4) Strong concentric ripples.

I shall attempt to explain these above attributes.

The stress trajectory afforded by the shear waves accounts for the typical cross-section of a resolved flake (Fig.6b). The prominence of the bulb of force results from a combination of: (1) the angle of coincidence of the downward propagating surface crack and the spheroid compressional pulse transmitted in the direction of the force vector (Fig.6b), (2) the large magnitude of force necessary to transmit the shear wave pulse into the body of the core along the line where fracture will occur.

The relative straightness of the resolved flake would likely be due to the particular pattern of shearing stress trajectories set up in the body of the core due to the angle of incidence of the force vector. A full explanation here would, again, involve mathematical treatment, and I am not able to make other than the above casual comment on stress trajectories.

The strong and closely spaced concentric ripples seen on a resolved flake are another result of a rapid, rather heavy blow (necessary in resolved flake production, for reasons indicated above) which sends out a strong pulse of great frequency. The stone material composing the hammer also aids in producing a high frequency wave, as mentioned in a previous section.

Of course, particular core shape will affect all of these above attributes, and Witthoft notes (n.d.:15) that resolved flakes (blades, in this case) at the Shoop site (Pennsylvania) were drawn from polyhedral, pyramidal cores with the pyramid apex used as the striking platform. The flat sides of a core prepared this way would also contribute to the flatness of a flake struck from it. In my opinion, only resolved flakes could be struck in any number from a core so prepared because of the cross-section of the resolved flake. This does not mean, however, that resolved flakes might not be struck from cores otherwise prepared.

Flat flaking, says Witthoft, produces the following formal attributes in a flake:

1) Long flake (often as long as the core).

2) Parallel edges.

3) Relatively constant cross-section, tapered from bulb end to distal.

4) More curvate than resolved flakes.

5) Ripples less numerous and pronounced than resolved flake.

6) Bulb of force less pronounced than resolved flake.

The immediately striking thing about this description of a flat flake is its similarity in several respects to the description of a blade or bladelet, and it is undoubtedly flat flaking which was employed in their manufacture (Witthoft n.d.:8).

In attempting to account for the above attributes as follows, I must once again fall back on a general reference to particular distribution of shearing stress trajectories due to the ninety degree angle of force vector incidence in flat flaking to explain the "long" attribute of the flat flake. With a carefully prepared core, the edges of the flake would be parallel because the line of fracture is relatively perpendicular to the platform, and the edges would not diverge as with a thickening resolved flake, nor converge, as with the sharply tapering cross-section of a free flake. The cross-section of the flake will narrow particularly to the end detached from the lower portion of the core, because it is here that the core itself is rounded or tapered to prevent opposition of force cones and resultant shatter. Ripples are less numerous and pronounced than seen in resolved flakes because the force necessary to cause fracture is less where the shear stress trajectory does not enter so deeply into the body of the core. Because the percussion blow is not so hard and rapid as it is for a resolved flake, plastic working or flow is not so advanced and the frequency of the maximum shear wave causing fracture is not so high in flat flaking; therefore less rippling is seen.

The lesser pronouncement of the bulb of force once more relates to two things: (1) the less heavy and rapid application of force, (2) the angle of coincidence of the surface crack with the compressive spheroid longitudinal wave front (Fig. 6c).

The platforms on all three kinds of flakes will be much bruised from the impact of the stone hammer (Witthoft n.d.:9).

Looking at the angle subtended by the striking (or pressure) platform of a flake and the side of the core as now represented on the outer side of the flake, one can, together with observing the curvature of the longitudinal cross-section of the flake, make a reasonably accurate estimate of the shape of the core from which the flake was derived (Fig. 7). Clues as to which of the three techniques of flaking (flat, resolved and free) above delineated was employed in the manufacture of a particular flake have been presented above, and an examination of these, in conjunction with the estimate of core shape and preparation, ought to give a fairly reliable picture of techniques leading up to the final production of a given flake.

A number of other experimenters in stone technology have made observations upon formal attributes of flakes which correlate with specific techniques of manufacture. I shall list various techniques and observations made by these people, and shall attempt my own explanation of the physical principles behind observed attributes.

Indirect Percussion. - The detaching of a flake from a core by means of striking an intermediary punch with a stone hammer leaves characteristic traits on the flake produced:

1) Small butt or platform remnant (Bordaz 1959: 48; Jelinek 1964: 5-6).
2) Pronounced bulb of force (Bordaz 1959: 48), less so than with direct percussion (Jelinek 1964: 5).
3) Grooved shatter lines (also seen in direct percussion). No source here, but seems likely that presence on flake is due to percussion (see page 33 of this text).
4) Frequent small ripples (Jelinek 1964: 5-6).
5) Curved in longitudinal cross-section.
6) Bulbar scar (s) (Jelinek 1964: 6).

Figure 8a represents the above characteristics on a flake derived by indirect percussion. I shall attempt below to explain the association of these attributes with indirect percussion.

With an intermediary punch, the initial area of contact with the core platform is much smaller than is the case with direct hammerstone or even baton percussion. The core volume encompassed by the maximum shear wave is thus initially of smaller dimension, and when fracture occurs the platform remaining on the detached flake is smaller than in direct percussion. This sort of pyramidal or <u>pointed</u> (MacNeish n.d.: 21) platform is a perfect example of shear fracture. By "pyramidal" I mean that the bulb end of the flake tapers to an apex which is the platform remnant (Fig.8a).

I would like to further note that the platform preparation (abrasion or flaking) often done to give the intermediary punch a better purchase on the platform would cause the platform area immediately around the point of force application to be heavily flawed, thus allowing for easy fracture or shattering of the platform according to principles previously outlined. Of course, on a flake where the platform has shattered and disappeared, it is not possible to determine whether or not it had been prepared. It would be very interesting (particularly with regard to obsidian), in controlled experiment, to note whether or not prepared platforms do shatter more readily than unprepared. At least, in a collection of flakes manufactured by indirect percussion, of those flakes with a large amount of platform remaining, there ought to be considerably more with unprepared than prepared platforms.

While the indirect percussion technique would bring about the same kind of spheroid compression (Fig. 4a) by longitudinal wave action (the basis for the bulb of force) seen to occur under all kinds of force application to isotropic media, one would expect the bulb to be smaller than that produced by direct percussion, as the spheroid wave is radiating out from a smaller area of force application when a punch is the applicator than when a hammerstone is employed.

If an antler or bone punch is used, this medium is less dense and rigidly elastic than is the stone hammer with which the punch is struck, and the pulse transmitted from the hammer through the punch should be less rapid at the contact with the core than it would be if the stone hammer alone were applied with a force of the same velocity directly to the core. However, in all likelihood (I have no archeological references to cite here) the hammerstone would be applied, by a knowledgeable stone worker, with more force to a punch than directly to a core platform, as the greater surface contact area of the direct percussion technique requires less force to produce fracture than would be required to produce the same fracture (i.e., detach the same flake) where force is applied to a smaller area (Stanworth 1950:67). One may, then, only say generally that at a given point on the inner surface of a flake, ripple marks produced by a direct hammerstone (or baton) blow ought to be wider in arc than if they had been produced by indirect percussion, as they originated from a larger surface of contact, where more surface particles are activated as a wave front. I do not believe that I can make any statement as to frequency of ripples (how closely spaced they are) exhibited by direct as opposed to indirect percussion techniques, but observation in practical experiment might easily determine this.

Grooved shatter lines were seen previously (page 33 of this text) in this text as resulting from violent or percussive fracturing. It has been suggested that these grooves represent escarpments between different planes of the same fracture moving in one direction (Stanworth 1950:73; Mackenzie 1962: 126) and the one microphotograph which I have seen (Laboratory of Anthropology, University of Manitoba) of this phenomenon appears to substantiate this idea.

Bulbar scars are D-shaped flake scars which originate from a grooved shatterline (Fig.2a), perhaps where this shatter mark has encountered, in the course of its development, an internal flaw of some nature (such as an air bubble) in the core material. Stress could already be present around this flaw, and when encountered by the developing shatter line, a fracture would radiate out from the flaw. Perhaps the exclusive occurrence of scars on bulbs has to do with the change in direction of fracture which takes place at that locus on the flake. Apparently only percussion techniques provide sufficient stress (or sufficiently rapidly applied stress) to cause bulbar scars, as they are not seen to occur on flakes detached by pressure, insofar as I may judge by the sources which I have employed.

It is interesting to note that when Jelinek was watching Francois Bordes detach flakes from an obsidian core by indirect percussion he noted: "The more the punch is tilted back from the edge of the core, the larger the bulb at the top of the blade. The more vertical the punch is held with respect to the striking platform, the smaller the bulb" (Jelinek 1964:6). This observation substantiates Witthoft's remarks, previously dealt with, on the bulbs resulting from free and flat flaking.

One might consistently detach thinner flakes by indirect rather than direct percussion techniques because of the relative ease of applying force to a chosen point by the former technique. Jelinek makes the observation (Jelinek 1964:8) that thinner flakes produced by indirect percussion are more strongly rippled than thicker flakes produced by the same technique. I would attribute this to the shear wave (causing eventual fracture) having to pass through less density of material where a thin flake is being struck off, and therefore being able to cause more plastic working of material immediately prior to fracture caused by the propagation of a crack. Some kind of increased interference from waves reflected from the core boundary (which is obviously closer to the strain and fracture line in a thin flake than a thick one from the same core) is undoubtedly involved here too, in a way precisely unknown. Crabtree notes (1966:12) that the intermediary punch must be pressed firmly with the hand holding it on to the core platform as the hammer blow is delivered to it, or a very pronounced bulb and severe rippling will occur. A blow of indirect percussion with a loosely held punch might result in a flake which looks as if it had been struck off by direct percussion, particularly if the platform does not remain. (This latter thought is mine and is no responsibility of Crabtree's).

It is further conceivable that where too much force is applied in indirect (or direct) percussion, not only will the platform completely shatter, but the blade might snap off cleanly, somewhere along its length, at right angles to the direction of the force vector, due to lateral <u>tensile</u> stresses (Bowden and Field 1964:336). With slow application of force, as by pressure, these stresses would have time to redistribute themselves and this kind of transverse fracture would be more likely avoided.

Small cores, such as those from which bladelets are struck, lack inertia due to their small weight and mass, and would require firm support for indirect percussion (Crabtree 1966:17). An anvil would be required, then, of antler, bone, wood or any "semi-yielding" (Crabtree 1966:17) material (possibly even packed earth) which would not deliver a bounce, or rebound blow from beneath and shatter the core or cause the flake to come off short (Semenov 1964:42). Stone is generally too rigid to serve as an anvil. It has been noted that when detaching primary flakes from a core, flaking control is maximized when the platform of the core is parallel to the anvil, or very nearly so (I clearly recall this being in print, but cannot locate the source).

Direct Percussion. - A flake detached by this stone hammer technique bears the following traits:

1) Very pronounced bulb of force. (Bordaz 1959:40)
2) Strong rippling. (Bordaz 1959:42)

3) Frequent bulbar scars. (I have no source to quote here, but I have noted numerous scars on large obsidian flakes from other collections, where the great size of the flake indicated it could only have been struck off by a heavy, direct blow).

4) Grooved shatter lines. (my own inference once again as under Indirect Percussion)

5) Relatively thick flake. (Bordaz 1959:42)

6) Curved in longitudinal cross-section (Semenov 1964:46)

Direct percussion with a wooden or antler billet or baton (differences in flakes obtained by implements of different materials is obscure) results in the following traits in a flake which are different from those produced by a stone hammer:

1) More flattened bulb. (Jelinek 1964:1)

2) Thinner blade. (Bordaz 1959:42)

3) Overhanging lip on platform. (Jelinek 1964:2).

I believe the presence of the flake attributes listed above as accompanying production by direct hammerstone percussion are explicable in terms of that portion of the above text explaining the correlation between indirect percussion and formal flake attributes. The relative thickness of these flakes is attributable to the necessity of striking the core platform with the hammerstone well back from the edge to prevent complete crushing of the edge. The shape of a hammerstone, of course, makes it impossible to hit a chosen point near the edge with accurracy.

I would hypothesize that the flatter bulb of antler billet percussion is likely due to the shape of the billet producing a spheroid wave (Fig. 4a) of initial larger radius. This together with the less compressive nature of the wave due to the relative lack of rigidity and elasticity of the antler material, cause the bulb to be more diffuse and not as salient as that produced by hammerstone percussion.

The comparative thinness of flakes detached by an antler billet derives from the fact that, by virtue of its shape, the billet cannot strike the core anywhere but right at, or immediately adjacent to, the edge of the core platform.

Jelinek noted that in the striking off of blades directly from an obsidian core, the antler baton produced a lip or overhang at the edge of a flake platform (Fig. 8b). This lip was absent in flakes detached directly by hammerstone percussion. I believe this attribute (presence of lip) relates to the kind of fracture seen previously in this text to be exhibited by glass when subjected to violent or percussive forces application (Fig. 3b), and have attempted to illustrate this parallel in Figure 8b. The lip would be formed by the initial small ovoid fracture (beginning at a surface flaw) seen in Figure 3b immediately under the surface, and the subsequent crack propagation would run around the line of the bulb of force and then change direction as an ultimate line of fracture (see Fig. 4a again). The eventual forking of fracture seen to take place in Figure 3b would not normally occur in flake detachment unless too great and rapid a force had been applied, and then fracture forking and shattering of the core might occur.

Hammerstone percussion would crush any lip produced in the above way, whereas the softer wood or antler baton would not. The presence of a lip is therefore noted only when blades are struck off by the baton technique.

Pressure Flaking. - Formal attributes present in flakes detached from a core by pressure are as follows:

1) Lesser bulb than by either percussion technique. (Semenov 1964: 33).
2) Ripples weakly developed. (Semenov 1964: 46).
3) Less curved longitudinal cross-section than percussion flakes (virtually straight, in fact).
4) Frequently long.
5) Platform most frequently intact, prepared or unprepared.

I would hypothesize that the slower application of force (though of great magnitude) in the pressure technique does not create the rapid spherical compression resulting in a prominent percussion bulb which is the result of percussive force application. The compression is diffused more down the length of the flake and a flat, diffused bulb is seen to result from the force of pressure.

I have noted elsewhere that plasticity is heightened with the rapidity of force application. In pressure flaking, the slowly applied force results in less plastic working and this, together with the low frequency of the shear wave produced by this technique, results in weakly defined and widely spaced ripple marks. The more rapidly pressure was applied in detaching a flake, the more evident rippling ought to be.

Semenov notes that, in isotropic materials, the fracture line is straighter when produced by pressure than when by percussion (Semenov 1964:46). In other words, the fracture is less conchoidal in the axis of flake length. Although I have not been able to find authorative references to this effect, it appears to me very possible that the curve of the maximum shearing stress trajectory in a body might be less under force slowly applied, as in pressure flaking, than under force applied rapidly, as in percussion flaking. Once again, I am sure any explanation of this phenomenon, if it is factual, would have to be brought forth in mathematical terms.

Because the fracture line is straighter, the flake detached along the side of the core will be longer than flakes would be if struck off the same core by direct or indirect percussion. It has been noted that the conchoidal nature of the fracture on micro-blades is hardly noticeable and likely due to pressure flaking (Semenov 1964: 54).

The slow application of force by pressure does not produce surface waves intense enough to shatter the platform, which remains intact.

One must note that the concepts of resolved, free and flat flaking may be combined, each in turn, with the concepts of pressure, direct percussion, and indirect percussion flaking. In both indirect percussion and pressure flaking, it would appear that less slippage of the punch and flaker, respectively, would occur if flat flaking were employed, but no doubt this advantage was often outweighed by the need felt by stone workers to produce a particular kind of flake which was not producible by flat flaking.

The El Inga Collection (Major Objective 4)

The materials comprising this collection were gathered during January and February of 1960 at the Ecuadorian Sierra site, El Inga, by Dr. W. J. Mayer-Oakes and Dr. Robert E. Bell. A description of the kinds and quantities of artifacts contained in the surface collection from the site may be found in a paper by Mayer-Oakes (1965), available at the Laboratory of Anthropology of the University of Manitoba, where part of the surface collection is also housed. Occupation of the site has been dated from 7,000 B.C. to 2,000 B.C. (Bell 1965:214).

Of the 48,238 objects (stone and pottery) collected at the site, 41,381 have been classified as debris or waste flakes. Obsidian pieces total 45,776 or ninety-eight per cent of the lithic material contained in the surface collection (Townsend 1966:8). Of these obsidian objects, between eight hundred and one thousand are flakes, which resemble in size and general configuration the bladelets previously described in this text as a particular type of flake derived from a special kind of core. The above rough approximation of numbers of these flakes relates to the incomplete stage of analysis at which the collection stood when Mayer-Oakes' 1965 paper was written. At that time 666 of the flakes had been analysed and described.

The term blade-like (I would prefer bladelet-like, though a more cumbersome term) has been employed by Mayer-Oakes to refer to these flakes, which have only roughly parallel edges and often very irregular facets on the outer side resulting from the prior detachment of other flakes. Figure 8a depicts a blade-like flake, from the collection, possessing the kinds of formal attributes described previously in this text as possibly associated with detached obsidian (and flint) flakes. Flakes range in shape (and inferred quality of workmanship) from very symmetrical parallel edged to highly irregular in morphology. This statement results from my own casual examination of the total collection and I have no numerical data here.

Of the total collection of flakes examined by spring 1965, eighty-four per cent exhibited working (and are termed <u>spokeshaves</u> by Mayer-Oakes) and sixteen per cent (<u>simple</u> blade-like flakes) did not. Unifacial working is highly predominant. Of the <u>spokeshave</u> flakes, thirty-one per cent possessed striking platforms. I note the foregoing, because platform description will figure very prominently in the analysis and description, which I shall attempt, of a sample of these flakes and ultimately in interpretation of flake attributes as results of specific manufacturing techniques.

I must mention at this point, that I intend to take a limited sample from the number of blade-like flakes in the collection, and to further deal with a limited number of formal attributes which I propose to be relatable to specific technique of manufacture. What I have in mind here is an illustration of the kind of thing which might be done with all the obsidian artifacts in the collection, but the analyses and correlations which I shall attempt will not be exhaustive by any means.

Some Archeological Concepts (Minor Objective 5)

In the first chapter of this text, I dealt briefly with the artifact _attribute_, defining it minimally as a trait or characteristic of any dimension of that artifact. Frankly, I am unable to expand this delimitation of the concept in any way which will make it more meaningful. It would seem that science in general has certain _primitive_ or basic terms which are no more definable for their being basic. The precise meaning of _trait_ or _characteristic_ in this context may be grasped only intuitively upon seeing repeatedly how and when the concept _attribute_ is employed in archeological literature. I believe one can say that the number of attributes of all dimensions possessed by any one artifact is limitless and relative to time and the knowledge plus imagination of the analyst. However, only a limited number of the range of attributes of an artifact would ever likely be pertinent to archeological research.

By way of example, on a projectile point a virtually infinite number of pairs of stipulated points may be joined by a straight line, and the length ratio of any one line to any other may be determined. Each of these ratios would in some way describe an aspect of the formal dimension of the point and would be a formal attribute. Only a very few of these ratios would be pertinent to the archeologist. One such ratio would be that of the line joining the tip of the point to the mid-point of the base to the line perpendicular to it which joins two points to represent the maximum width of the point.

This leads to a distinction between metrical attributes and discrete attributes. The former are continuous in nature; a section out of a continuum. For example the attribute "three inches in length" is obviously of the metrical kind and so is the generalized concept "length" a metrical one. Discrete attributes, on the other hand, are measured only by presence or absence; an artifact is round or it is not, and it is yellow or it is not. Actually, discrete attributes dissolve into metrical ones if you look closely enough. Color is a metrical function of reflected light wave lengths and roundness is a geometrical and mathematical ratio of lineality. In spite of this, the categories discrete and metrical are convenient ways to look at attributes for purposes of artifact analysis.

It is worth noting that an attribute may be negative as well as positive. To say that a particular artifact is not round _may_ be more significant than a description of its actual shape, or further, the lack of ripples on a blade is an attribute.

It has been noted (Mayer-Oakes 1966b:4) that one can make a case for combining certain discrete and metrical artifact attributes into _artifact systems._ For example, _striking platform_ (itself a discrete attribute by definition) where present might be viewed as an artifact system reducible into several more specific attributes of either a discrete or metrical nature. _Prepared_ is a discrete attribute, while _maximum width_ is of course metrical.

As it appears unlikely that the concept artifact _attribute_ will ever be subject to anything but an intuitive kind of delimitation, I do not believe the consideration of some discrete attributes as comprising an attribute system will cloud any issues of conceptual polemic. It appears, in fact, to be a useful way to think about organization of analytical tools.

The nature of the artifact type continues to be a bone of contention among archeologists, as evidenced by the relative frequency in the literature of articles dealing with this concept. Do types exist in artifact assemblages and may they be derived by a statistical analysis of the frequency of attributes in an assemblage? Albert C. Spaulding would reply affirmatively to both parts of this question (Spaulding 1953). Others see artifact types as arbitrary abstract groupings created by the archeologist, the defining attributes of which are selected according to whatever archeological objective the selector wishes the resultant artifact type to serve (Rouse 1960:315-317). The problem of the nature of the type in archeology is not just a tangential exercise in metaphysics, as the decision made by an archeologist as to what a type really is will greatly affect the way in which he handles data where classification is concerned.

As previously stated, I shall be working with a few selected flake attributes in an attempt to relate them to technology. It is clear, then, that I am not concerned with deriving a taxonomic classification of the materials in the El Inga collection and that the taxonomic unit type as viewed by either Spaulding or Rouse is not a suitable concept for working with these attributes.

It would immediately appear that the concept mode, as developed by Irving Rouse, might be a valid term to apply to the kind of attributes (such as ripple marks, shatter lines) with which I have dealt and shall further deal. Rouse defines a mode as "any community wide standard, concept or custom which governs the behavior of the artisans of a community.... Such modes will be reflected in the artifacts as attributes...." (Rouse 1960:313). Attributes which relate merely to biological, chemical or physical aspects of artifacts may not be considered as modes, which must have a cultural significance by definition.

Rouse distinguishes (1960:315) between conceptual modes and procedural modes, the latter referring to customary ways of making and using artifacts. Conceptual modes are those relating to such attributes as material and shape. With reference to El Inga blade-like flakes, it is clear that formal attributes such as obsidian or particular range of angle of striking platform to the side of the flake (reflecting core shape) might be employed as conceptual modes if the archeologist believes their presence in the collection is culturally significant and wishes to employ them to achieve a particular research objective. It is equally obvious that platform preparation, or the lack of it, might be employed as a procedural mode. Prepared platform is, I believe, a good example of what Rouse means when he says the procedural modes must be accompanied by inference upon behaviour of artisans (1960:315). The recurrence, in a collection of blades, of abrasion or chipping on the platform of a flake would have to be interpreted as deliberate preparation of the platform rather than an incidental and/or accidental phenomenon.

Do attributes such as ripple marks, grooved shatter lines or prominent bulb of force reflect a standard, custom or concept to which an artisan has conformed? Or are they more accurately viewed as "within the realm of .... physics rather than culture" (Rouse 1960:313), That is, are they attributes which may be employed as modes if so desired? I have previously indicated that strong ripple marking and shatter lines are both results of the derivation of a flake by percussion. If percussion flaking is a procedural mode (and I believe it qualifies as one, by definition), then what are the formal attributes resulting from this technique to be termed? Strictly speaking, they are only traits of physics in a particular kind of medium, and do not directly relate to artisan standards, concepts or customs. Yet they are a direct result of a specific technique which may well qualify as a mode should the archeologist wish it.

Because, by Rouse's definition of mode, the archeologist is allowed to judge whether an attribute is culturally relevant and may be used as a mode, I shall assume that an attribute such as strong ripple marking does qualify as such, being an indirect consequence of specific cultural behaviour. To the mode concept has accrued some of the haziness of its root, the <u>attribute</u>.

Rouse has further indicated that taxonomic classification (artifact types) is only one of two possible ways to classify groups of artifacts according to modes set up among them (Rouse 1960: 315). The procedure termed <u>analytic classification</u> entails the classification of artifacts into groups, each of which is characterized by modes of a specific kind, such as technological, or stylistic (shape and decoration) or functional.

Each class is derived successively, that is, artifacts will be classified by technological modes in various groups, which are next reclassified according to style, and so on (see Fig. 2, Rouse 1960:315). The modes with which I am to deal are indisputably technological. Technological modes might be drawn from both conceptual modes (material, for example) and procedural modes.

A summary of the foregoing presentation of aspects of archeological theoretical concepts might prove helpful. The concept <u>attribute</u> has been presented as twofold in kind, there being both discrete and metrical attributes. Certain discrete attributes of a general nature may be viewed as an attribute system comprised of a series of more specific discrete and metrical attributes. It was seen that the problematical concept of artifact type may be considered as inherent in artifact assemblages or, on the other hand, as arbitrary abstract groupings, depending upon which theoretician one chooses to comply with. The concept of mode as developed by Irving Rouse and as employed in analytical classification is viewed by this writer as suitable conceptually for the analysis of the El Inga collection sample to be handled. The term "indirect percussion flake", for example, would then represent one technological, analytical class of flakes from the El Inga collection.

Figure 9 represents graphically the procedure of analytical classification dealt with above. Here, a collection or assemblage of artifacts is subjected to analysis, and the metrical and discrete attributes of each artifact analysed. The archeologist then chooses as modes those artifact attributes which he considers culturally significant and pertinent to his research objective. Modes may be technological, stylistic, functional, or perhaps of other categories. In Figure 9, artifacts are finally placed together into one technological class on the basis of their common possession of one or more technological modes. Clearly, further analytical classes might be set up employing the same artifacts, but basing classification on stylistic or functional nature.

Attribute List for Analysis of Collection Sample (Minor Objective 6)

I have taken, as a sample from the El Inga collection, 297 blade-like flakes all of which possess striking platforms. Apart from a few flakes which are temporarily separated from the collection for illustration and thus unavailable to me, the 297 flakes represent the total number of blade-like flakes possessing striking (or possibly pressure) platforms. A goodly number of flakes are broken off at the distal end, but most all are complete enough to give one a clear picture of the original total morphology.

The distribution of these flakes as to classification as spokeshaves or simple flakes and as possessing prepared or unprepared platforms has been determined by analysis previous to mine, and is as follows in Table I.

TABLE I

Distribution of 297 Flake Sample As To Working and Platform Preparation

	Prepared Platform	Unprepared Platform	Total
Spokeshave	110	115	225
Simple Flake	46	26	72
Total	156	141	297

The number of flakes possessing platforms was small enough that I did not feel the need to take a random sample from them, but rather chose to work with the total number. I might note here that the two major classes (spokeshave and simple flake) and four sub-classes of Table I are analytical (rather than typological) classes based on technological kinds of procedural and conceptual modes.

Previously in this text I have listed some of the formal flake attributes which are seen to be associated with techniques of direct percussion, indirect percussion and pressure flaking respectively. I shall attempt to determine the frequency of these attributes, each singly, in the 297 blade sample and to note the frequencies of the various combinations in which these attributes occur. Statistical techniques will next be employed to determine what significance, if any, the distribution of observed attribute combinations holds.

Secondly, I have heretofore indicated (pages 60-61 of this text) an interest in determining whether or not prepared platforms shatter more easily than do unprepared platforms. The hypothesis which I formerly stated is that of those flakes with a large amount of platform remaining, there ought to be considerably more with unprepared than prepared platforms. To this end, flake attributes involving platform completeness and shape are of interest to me. Figure 10 represents what I have termed an attribute list for analytically classifying the 297 blade-like flakes according to modes which I have deliberately chosen for what to me is their technological significance. These particular modes have been chosen as suitable for the two above outlined objectives of analytical classification, determining the significance of combinations of formal attributes specifically associated with percussion techniques and investigating the relationship between platform size and shape and platform preparation. It is important to note here that these two objectives are only examples of the kinds of questions one might ask of primary archeological data on lithic materials, when specific consideration is given to the physical principles associated with various techniques of stone technology. Obviously, a great many objectives may be posed other than those developed here.

CHAPTER III

OPERATION 3 - DESCRIPTION

Major Objective

In this operation, the major objective is to describe the 297 blade-like flakes comprising the primary data of the previous operation. Description will, of course, be conducted in the light of the two limited objectives posed in Operation 2:

1) a determination of the frequencies of single attributes which I have indicated as associated with particular techniques of flake manufacture and an eventual statement of frequencies of observed combination of attributes in terms of their statistical significance.

2) a determination of correlations between platform shape and size, and platform preparation, to be later checked for statistical significance.

Method

The method of implementing the above major objective may be achieved by the accomplishment of three minor objectives:

1) Application of the conceptual framework to

the 297 flakes, and a description of the flakes in terms of these attributes.

2) Presentation of tables designating observed and expected frequencies of single attributes and their various combinations.

3) Application of statistical devices to the Tables of 2) above in order to state the significance of the observed frequencies in terms of probability theory.

Application of Conceptual Framework to 297 Flakes

Ideally, 297 copies of Figure 10 would be obtained, and the appropriate combinations of letter and number (A1, B2, C1....for example) would be checked off on a single copy for each flake. The 297 check lists having been completed (all flakes examined), the information would then be transferred to IBM punch cards and frequencies of single attributes and attribute combinations determined by running the cards through a card sorting machine. As delay may be encountered in having cards punched, I chose to make a manual tally of attributes and their combinations, which, with 297 flakes and the limited list of possible attributes in Figure 10, is not too formidable a task. I would, however, like to have, eventually, the above information on the flakes recorded on punch cards for ease of storing and future use. A description of each of the 297 catalogued flakes in terms of the formal attributes listed in Figure 10 is presented in tabular form in an appendix to this text.

Table II represents observed frequencies of these attributes directly relatable to either direct percussion, indirect percussion or pressure flaking. Attribute D is absent here as it was not considered previously under the "Experimental Results" section.

TABLE II

Observed Frequencies of Attributes A, B, C, E and F*

	Attributes														
	A Ripple Marks			B Grooved Shatter Lines		C Platform Shape			E Curvature				F Bulb		
	1	2	3	1	2	1	2	3	1	2	3	4	1	2	3
Frequency	290	5	2	296	1	43	245	9	4	35	174	84	1	255	41
Total	297			297		297			297				297		

* See Figure 10 in conjunction with this Table

Table III indicates the twenty-four different attribute combinations observed in the examination of the 297 blade-like flakes. The first column headed O represents the actual observed frequency in the sample of each attribute combination. Column E represents the expected frequency of each combination of attributes, that is, the number of times one would expect a combination to occur while assuming that each component attribute is an independent entity, not depending upon the presence of any other for its occurrence. The expected frequency of each combination is derived as follows, taking combination A1B1C1E1F1 as an example:

$$\frac{290}{297} \times \frac{296}{297} \times \frac{43}{297} \times \frac{4}{297} \times \frac{1}{297} \times 297 = \text{Expected Frequency}$$

Column three is a computation necessary for the completion of the fourth column. The meaning of column four is very difficult to express, and I shall merely state that the sum total of all the numbers appearing in column four is the Chi-square (X^2) of Table III. Behind this Chi-square calculation exists the hypothesis that the 297 flakes represent a sample from an unknown population of flakes and the difference seen between the distribution of observed and expected frequencies of attribute combinations may be explained as the result of imperfect sampling techniques or of chance.

TABLE III

Attribute Association Analysis for 297 Flakes

Attribute Combination	O	E	O-E	$\frac{(O-E)^2}{E}$
A1B1C1E1F2	1	.73		
A1B1C1E2F2	3	4.187	-.900	0.1650
A1B1C1E3F2	17	20.90	-3.581	0 .5940
A1B1C1E3F3	1	.681		
A1B1C1E4F2	20	10.09	11.28	10.8560
A1B1C1E4F3	3	1.63		
A1B1C2E1F2	1	.74		
A1B1C2E1F3	1	.12		
A1B1C2E2F2	15	6.77	15.15	25.9340
A1B1C2E2F3	6	1.10		
A1B1C2E3F1	1	.12		
A1B1C2E3F2	144	119.84	24.16	4.870
A1B1C2E3F3	14	5.43	8.57	13.525
A1B1C2E4F2	39	57.40		
A1B1C2E4F3	14	2.61	-5.87	0.5660
A1B1C3E2F2	2	.86		
A1B1C3E3F2	2	4.36		
A1B1C3E4F2	5	2.08		
A1B2C2E1F3	1	0	6.56	5.1000
A2B1C1E4F2	1	.15		
A2B1C2E3F2	3	.74		
A2B1C2E3F3	1	0		
A3B1C2E3F2	1	.75		
A3B1C2E4F2	1	.36		
all others (192)	0	55.4	-55.4	55.400
	297	297	0	X^2=117.01
				d.f.=8

Probability (less than) .001

There are 216 possible combinations of the variants of attributes A, B, C, E and F. Only twenty-four of these are present in the sample. The combination "all others" appearing in Table III refers to those 192 possible combinations of attributes being dealt with which did not appear in the sample analysis, but which must be taken into consideration for statistical purposes. This kind of statistical comparison of the distribution of observed frequencies and of theoretical or expected frequencies is known as a "goodness of fit" test. In such tests, it is quite common to work at a .05 level of significance with respect to probability. That is, when the probability value is .05 or less (as indicated in a Chi-square table) the probability that the Chi-square statement of the differences between observed frequencies distribution and expected frequencies distribution is due to vagaries of sampling technique or chance is considered to be so small (5 out of 100, or less) that this difference must be significant. The null hypothesis to be stated with reference to Table III is that there is no difference between the distribution curves of the observed and expected frequency columns which may not be explained as due to sampling variation or chance. The null hypothesis must be rejected if the probability value given by the Chi-square calculation is .05 or less (accepting here .05 as the level of significance). It must be noted here that the rejection of this hypothesis does not explain what the forces are at work to produce an observed frequency distribution considered statistically to be significantly different from expected frequency distribution. For Table III when the Chi-square probability test is applied at the .05 level of significance, it is found that the null hypothesis must be rejected, and that the differences in O and E frequency distributions must be viewed as significant.

Table IV relates to the objective of determining a correlation between particular platform shape and platform preparation. The Chi-square calculation for this

TABLE IV

Chi-square Association Analysis for Attributes C2 and D1

	D1	other D	Total
C2	156	89	245
other C	0	52	52
Total	156	141	297

$X^2 = 69.7$

d.f. = 1

Probability (less than) .001

table is a test of the hypothesis that attributes C2 (pyramidal and small platform) and D1 (prepared platform) are independent variables and are not significantly associated in attribute combinations.

Table V will test the relationship between attributes C1 (complete and undamaged platform) and D2 (unprepared platform). The hypothesis here is that C1 and D2 are independent attributes. .05 level of significance is employed here. The probability value of the Chi-square calculated for this table indicates that the hypothesis of independence of C1 and D2 must be rejected.

TABLE V

Chi-square Association Analysis for Attributes C1 and D2

	D2	other D	Total
C1	31	12	43
other C	110	144	254
Total	141	156	297

$X^2 = 12.22$

d.f. = 1

Probability (less than) .001

CHAPTER IV

OPERATION 4 - INTERPRETATION

Major Objective

The major objective of this Interpretation operation is the interpretation of the attribute combination frequencies handled statistically in Operation 3 as culturally significant and relatable to specific manufacturing techniques.

Method

1) Interpretation of the data contained in Tables II and III as indicative of specific technological practices.

2) Interpretation of the data of Tables IV and V as the results of specific technology and reflective of the nature of obsidian (glass) fracture.

Table III and the probability value obtained from it have caused a rejection of the hypothesis that the difference between observed and expected frequency distributions are due to sampling fluctuations or chance. I interpret the statistical significance of this difference to be the result of a specific and deliberate technique of flake manufacture, indirect percussion, for reasons set out below.

The attribute combination with the highest frequency is A1B1C2E3F2, as would be expected from the frequencies in the collection of each individual attribute. The observed frequency of this combination is significantly higher than the expected frequency. Here, one must take into account the fact that the frequency of this combination was very likely substantially lowered by broken blades where curvature (attribute E) was indeterminate resulting in combination A1B1C2E4F2 with an observed frequency of 39 (significantly below its expected frequency of 57.4).

In terms of particular attributes, this combination A1B1C2E3F2 represents: (1) pronounced and frequent ripple marks, (2) presence of grooved shatter lines, (3) small and pyramidal platform, (4) moderate to pronounced curvature, (5) pronounced bulb.

Each of these attributes has been described elsewhere as resulting from the technique of percussion, and in the case of E3, from indirect percussion. I therefore interpret the contents of Table III as indicative of an indirect percussion industry which resulted in the production of at least the major portion of the 297 blade-like flakes examined.

I should like to add that, although I feel it methodologically necessary to run a "goodness of fit" test on the data of Table III, inspection of the observed frequency column alone of this table clearly indicates that the modal combination of the distribution curve, A1B1C2E3F2, is an overwhelmingly significant combination of attributes.

Assuming now that I am dealing with an indirect percussion industry, I shall attempt to interpret the statistical information in the remaining tables. Associations between attributes C2 and D1, and between C1 and D2 are both shown to be highly significant. C2, a pointed or pyramidal platform remnant (as in Figure 8a) is very significantly associated with D1, prepared platform, because platform preparation produces a myriad of flaws in the platform surface, resulting in an easy shattering of the platform under applied force.

C1, a complete and relatively undamaged platform is very significantly associated with D2, unprepared platform, as the lack of flaws which are produced by preparation has resulted in a greater ability to resist applied stress occasioned by the transmission of surface waves across the platform subsequent to and during applied force.

The above are only examples (which happened to catch my interest) of interpretations regarding technology and the reason for the presence of specific formal attributes of artifacts. Many other formal traits are equally worthy of attention as to their individual occurrence and their combination with other attributes. Let me once more conclude that the number of attributes holding technological significance for any archeologist is directly proportional to his awareness of the physical principles behind the presence or absence of those attributes.

Other attributes and combinations which might be examined for their technological significance are presented in the following operation.

Conclusion

I believe that in demonstrating in Operation 3 that specific artifact attributes seen associated with specific manufacturing techniques may be explained by reference to principles of force transmission in solids, I have substantiated Hypothesis I of Operation I, Problem Formulation.

In completing this present Operation 4, I believe I have made acceptable the second hypothesis of Operation I, that a statistical handling of observed frequencies of combinations of attributes demonstrated to be technologically significant would make possible an interpretation of these frequencies as resulting from a preferred technique of manufacture. The attribute combination A1B1C2E3F2, each component of which was seen to be associatable with indirect percussion, was overwhelmingly present in observed frequency. This fact, together with the Chi-square demonstration that the distribution of observed frequencies of all attribute combinations was most unlikely to be due to problems of sampling or chance, has enabled me to infer the presence, in the El Inga collection, of a manufacturer's preference for the technique of indirect percussion.

The correlations attempted between particular kinds of platform preparation and size and shape of platform represent an example of the kind of hunches one gets about which attributes might be associated, when one has even a slight knowledge of principles of force transmission, fracture and so on. Had I not been aware, through thesis research, that all glasses fracture from surface flaws, the relationship between the preparing (by abrasion or by chipping) of a platform and the size and shape of the platform remnant on a flake would not likely have occurred to me.

CHAPTER V

OPERATION 5 - NEW PROBLEMS

Major Objective

The presentation of attribute combinations, other than those previously dealt with, which might be technologically significant.

Minor Objective 1

It was noticed while analysing the El Inga collection sample of 297 blade-like flakes that a rather high proportion of hinge fractures were evident when dealing with attribute E, blade curvature. Hinge fractures were called, under E4, "curvature indeterminate".

I believe it would be worthwhile to investigate whether or not there is any statistically significant association between hinge fracturing and the angle subtended by the striking platform and the outer side of the flake. That is, is there any relationship between a specific general core shape and a high frequency of hinge fracturing? If so, this might indicate that this particular kind of core shape is difficult to work with.

Minor Objective 2

The ratio of width to length of complete flakes might be investigated to see if there are any statistically significant groupings of width: length ratios, which would be indicative of deliberate manufacture of flakes of two or more specific shapes, possibly for different intended usages.

APPENDIX

Description of 297 Flakes in
Terms of Figure 10 Attributes

Cat. No.	Attributes A	B	C	D	E	F
781	1	1	2	2	3	2
100	1	1	2	2	3	2
257	1	1	1	2	4	2
95	1	1	2	2	3	2
4	1	1	1	2	3	3
28	1	1	1	2	3	2
103	1	1	2	2	4	2
247	1	1	2	2	3	2
71	1	1	2	2	3	2
511	1	1	2	2	3	2
96	1	1	2	2	3	3
514	1	1	2	2	3	2
604	1	1	2	2	3	3
56	1	1	2	2	3	2
472	1	1	2	2	3	2
571	1	1	1	2	3	2
2	1	1	2	2	3	2
459	1	1	2	2	4	2
1	1	1	2	2	3	2
125	1	1	2	2	2	3
522	1	1	3	1	4	2
605	1	1	2	1	3	2
405	1	1	2	1	3	2
422	1	1	2	1	3	2
368	1	1	2	1	3	2
526	1	1	2	1	3	2
483	1	1	2	1	3	2
452	1	1	2	1	3	2

Cat. No.	Attributes A	B	C	D	E	F
603	1	1	1	1	3	2
541	1	1	2	1	3	2
99	1	1	2	1	3	2
188	1	1	2	1	3	2
70	1	1	2	1	3	2
8	1	1	2	1	3	2
19	1	1	2	1	3	2
224	1	1	2	1	3	2
218	1	1	2	1	3	2
219	1	1	2	1	2	2
74	1	1	2	1	3	2
308	1	1	2	1	3	2
298	1	1	2	1	2	2
553	1	1	2	1	3	2
290	1	1	2	1	3	2
18	1	1	2	1	3	2
241	1	1	2	1	4	2
27	1	1	2	1	3	2
303	1	1	2	1	3	2
239	1	1	3	1	3	2
596	1	1	3	1	4	2
34	1	1	2	1	3	2
26	1	1	1	1	2	2
305	1	1	2	1	4	2
114	1	1	2	1	3	3
181	1	1	2	1	3	2
314	1	1	2	1	3	2
550	1	1	2	1	3	2

Cat. No.	A	B	C	D	E	F
173	1	1	1	1	3	2
179	1	1	2	1	3	2
219	1	1	2	1	3	2
72	1	1	2	1	3	2
383	1	1	2	1	3	2
166	1	1	2	1	3	2
9	1	1	2	1	4	2
352	1	1	2	1	4	2
111	1	1	2	1	3	2
24	1	1	2	1	3	2
244	1	1	3	1	4	2
15	1	1	2	1	3	2
46	1	1	2	1	3	2
32	1	1	2	1	3	2
311	1	1	1	1	3	2
30	1	1	2	1	4	2
51	1	1	2	1	3	2
427	1	1	2	1	3	2
114	1	1	2	1	3	2
167	1	1	2	1	3	3
171	1	1	2	1	3	2
573	1	1	1	1	4	2
170	1	1	2	1	3	2
307	1	1	3	1	4	2
294	1	1	2	1	3	2
508	1	1	2	1	3	2
190	1	1	2	1	3	2
225	1	1	2	1	3	2
104	1	1	2	1	3	2
58	1	1	2	1	3	2
292	1	1	2	1	4	2
320	1	1	3	1	3	2
474	1	1	2	1	3	2
61	1	1	2	1	3	2
166	1	1	2	1	3	2
578	1	1	1	1	4	2
238	1	1	1	1	4	2
16	1	1	2	1	3	2
558	1	1	2	1	3	2
309	1	1	2	1	4	2

Cat. No.	A	B	C	D	E	F
221	1	1	2	1	2	3
50	1	1	2	1	3	2
17	1	1	2	1	3	2
503	1	1	2	1	1	3
601	1	1	2	2	4	3
19	1	1	2	1	3	3
531	1	1	2	1	3	2
533	1	1	2	1	3	2
103	1	1	2	2	3	2
99	1	1	2	2	2	2
598	1	1	2	2	3	2
591	1	1	1	2	3	2
477	1	1	2	2	3	3
473	1	1	2	2	4	3
284	1	1	2	1	3	2
169	1	1	2	1	1	2
258	1	1	2	1	2	2
217	1	1	2	1	3	2
43	1	1	2	1	4	2
85	1	1	2	1	4	2
183	1	1	2	1	3	2
70	1	1	2	1	4	2
595	1	1	2	1	3	2
222	1	1	2	1	4	2
319	1	1	2	1	4	2
54	1	1	2	1	3	2
469	1	1	2	1	3	3
73	1	1	2	1	3	2
468	1	1	2	1	3	2
88	1	1	2	1	3	2
14	1	1	2	1	3	2
42	1	1	2	1	3	2
482	1	1	2	1	3	3
454	1	1	2	1	4	2
100	1	1	2	1	3	2
70	1	1	2	1	3	3
91	1	1	1	1	4	3
48	1	1	2	1	3	2
600	1	1	2	1	4	2
107	1	1	2	1	3	2

Cat. No.	A	B	C	D	E	F
410	1	1	2	1	4	2
475	1	1	2	1	4	3
502	1	1	2	1	2	2
65	1	1	2	1	3	2
576	1	1	2	1	3	2
106	1	1	2	1	3	2
12	1	1	2	1	4	3
536	1	1	2	1	4	2
?(1?)	1	1	2	1	3	2
57	1	1	2	1	4	2
17	1	1	2	2	3	2
234	1	1	2	2	3	3
54	1	1	2	2	4	2
65	1	1	2	2	4	3
67	1	1	2	2	3	3
317	1	1	2	2	4	2
318	1	1	2	2	4	3
295	1	1	2	2	3	2
433	1	1	2	1	4	2
568	1	1	2	1	4	3
25	1	1	2	1	4	3
7	1	1	2	1	3	2
398	1	1	2	1	3	3
50	1	1	2	1	3	2
34	1	1	2	1	4	3
261	1	1	2	1	4	2
561	1	1	2	1	3	1
98	1	1	2	1	4	2
34	1	1	2	1	3	2
220	1	1	2	1	4	2
40	1	1	2	1	3	2
64	1	1	2	1	3	2
11	1	1	2	1	4	2
22	1	1	2	1	3	2
37	1	1	2	1	3	2
263	1	1	2	1	2	2
61	1	1	2	1	2	2
23	1	1	2	1	3	2
15	1	1	2	1	2	3
555	1	1	2	1	3	2
69	1	1	2	1	4	2
195	1	1	2	1	2	2
5	1	1	1	1	1	2
361	1	1	2	1	4	3
196	1	1	2	1	4	2
27	1	1	2	1	4	2

Cat. No.	A	B	C	D	E	F
2	1	1	2	1	3	2
59	1	1	2	1	3	3
547	1	1	2	1	3	2
10	1	1	2	1	3	2
523	1	1	1	1	4	2
504	1	1	2	1	2	2
82	1	1	2	1	3	2
94	2	1	2	1	3	3
115	1	1	2	1	3	2
80	1	1	2	1	4	2
512	1	1	2	1	4	2
12	1	1	2	1	3	2
461	1	1	1	1	4	2
572	1	1	1	1	4	2
453	1	1	2	1	3	2
480	1	1	2	1	4	2
408	1	1	2	1	3	2
458	1	1	2	1	3	2
21	1	1	2	1	4	3
91	1	1	2	1	3	2
16	1	1	2	1	3	2
19	1	1	2	1	3	2
545	1	1	2	1	2	3
86	1	1	2	1	3	2
492	1	1	2	1	3	3
493	1	1	2	1	3	2
288	1	1	1	2	4	2
39	1	1	2	2	3	2
294	1	1	2	2	3	2
228	1	1	1	2	3	2
36	1	1	1	2	3	2
17	1	1	1	2	3	2
293	1	1	2	2	3	2
315	1	1	1	2	4	2
106	1	1	2	2	3	2
69	1	1	2	2	3	2
297	1	1	2	2	4	2
230	1	1	1	2	3	2
296	1	1	3	2	4	2
38	1	1	2	2	2	2
251	1	1	3	2	2	2
226	1	1	2	2	3	2
38	1	1	1	2	4	2
233	1	1	2	2	3	2
287	1	1	2	2	3	2
208	1	1	2	2	3	2

Cat. No.	A	B	C	D	E	F
229	1	1	1	2	3	2
65	1	1	2	2	3	2
300	1	1	1	2	3	2
10	1	1	2	2	3	2
25	1	1	1	2	4	2
378	1	1	2	2	2	3
120	1	1	2	2	4	3
316	1	1	2	2	4	3
592	1	1	2	2	4	3
56	1	1	2	2	3	2
58	1	1	2	2	3	2
304	1	1	2	2	4	2
63	1	1	1	2	4	2
24	1	1	2	2	3	2
48	1	1	2	2	2	2
57	1	1	2	2	2	2
289	1	1	2	2	3	2
278	1	1	1	2	4	2
35	1	1	2	2	3	2
179	1	1	2	2	4	2
168	1	1	1	2	4	2
2	1	1	2	2	3	2
74	1	1	2	2	3	2
554	1	1	2	2	3	2
286	3	1	2	2	4	2
312	1	1	2	2	2	2
302	1	1	3	2	2	2
310	1	1	2	2	4	2
28	2	1	2	2	3	2
18	1	1	2	2	3	2
14	1	1	2	2	3	2
89	1	1	1	2	4	2

Cat. No.	A	B	C	D	E	F
185	1	1	1	2	3	2
33	1	1	1	2	4	2
101	3	1	2	2	3	2
23	1	1	2	2	3	2
84	1	1	2	2	2	2
14	1	1	2	2	3	2
20	1	1	1	2	4	3
72	1	2	2	2	1	3
18	1	1	2	2	3	2
594	1	1	1	2	2	2
64	1	1	2	2	4	2
235	1	1	2	2	3	2
227	1	1	1	2	4	2
194	1	1	2	2	2	2
563	2	1	2	2	3	2
223	1	1	1	2	4	2
242	1	1	2	2	2	2
57	1	1	2	2	3	2
321	1	1	1	2	4	2
53	1	1	2	2	3	2
23	1	1	2	2	3	2
45	1	1	1	2	4	2
559	1	1	2	2	4	2
567	1	1	1	2	2	2
178	1	1	2	2	3	2
207	2	1	2	2	3	2
306	2	1	1	2	4	2
481	1	1	2	2	2	2
177	1	1	1	1	4	2
71	1	1	1	2	4	2
565	1	1	2	2	4	2
193	1	1	1	2	4	3
6	1	1	2	2	2	3

Flakes have been listed in Appendix above in the order in which they were analysed.

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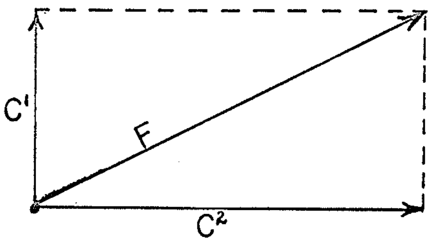
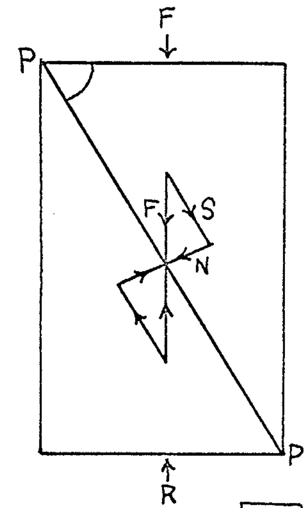


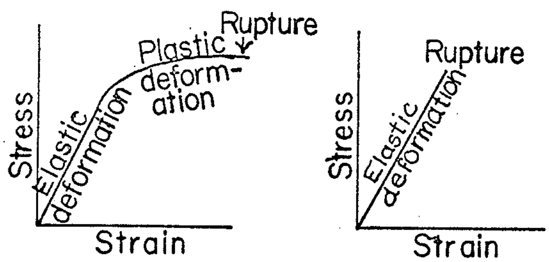
1a

RESOLUTION OF FORCE F INTO TWO COMPONENTS, C' AND C²



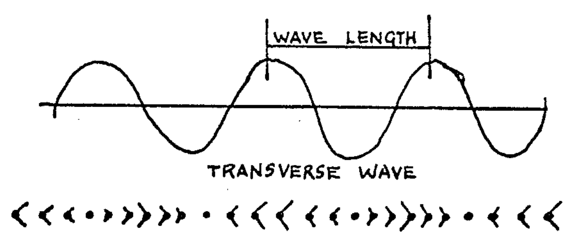
1b

STRESSES IN A BODY ACTING UPON PLANE SURFACE PP UNDER APPLIED FORCE F



1c

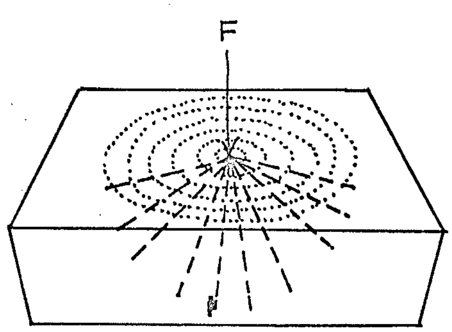
DUCTILE MATERIALS BRITTLE MATERIALS



TRANSVERSE WAVE

LONGITUDINAL WAVE

1d



1e

PROPAGATION OF A SURFACE WAVE IN AN ELASTIC MEDIUM

FIGURE 1

TRANSMISSION OF FORCE IN ELASTIC MEDIA

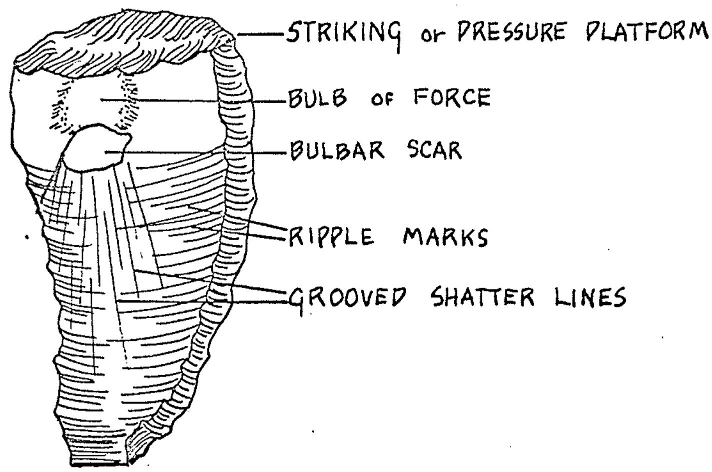


FIGURE 2a

CONCHOIDAL FLAKE FROM AN ISOTROPIC MATERIAL

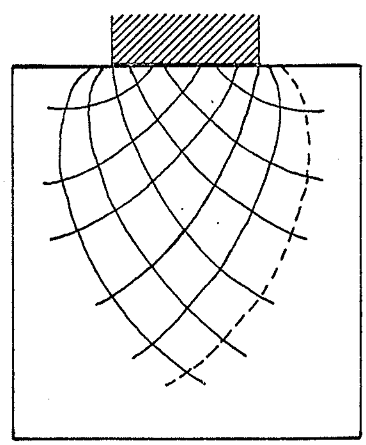


FIGURE 2b

CONCHOIDAL FRACTURE EXPLAINED BY MAXIMUM SHEAR STRESS TRAJECTORIES SEEN IN PHOTOELASTIC EXPERIMENTS. (AFTER NADAI 1931)

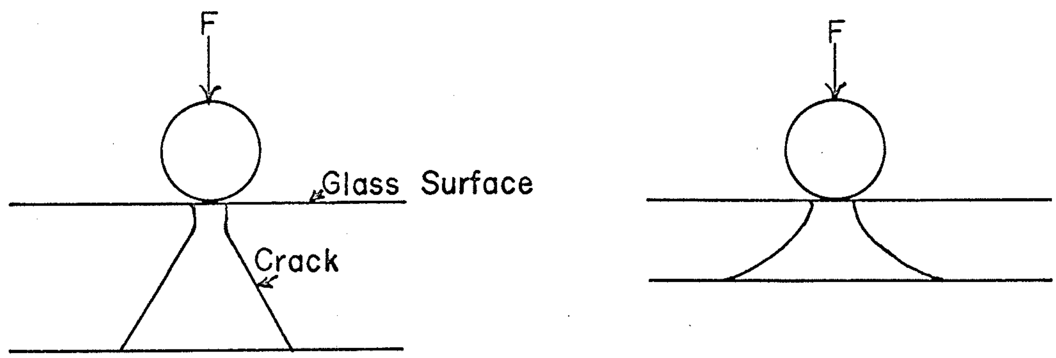


FIGURE 3a

CONICAL SHEAR FRACTURE OF GLASS PLATE

GREATER ANGLE OF SHEAR FRACTURE IN THINNER GLASS PLATE

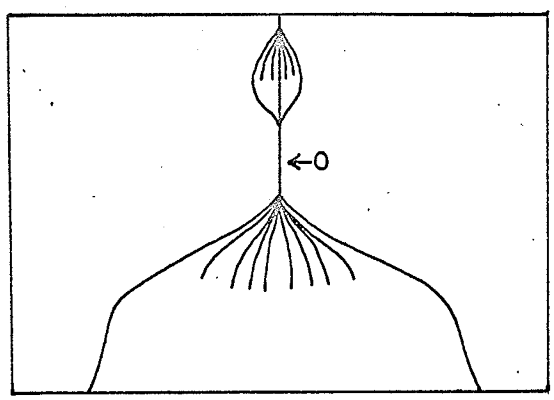


FIGURE 3b

FORKED FRACTURE OF GLASS CAUSED BY RAPID OR VIOLENT EXPLOSION DUE TO HEATING WITH FRACTURE ORIGIN AT O.
(AFTER STANWORTH 1958)

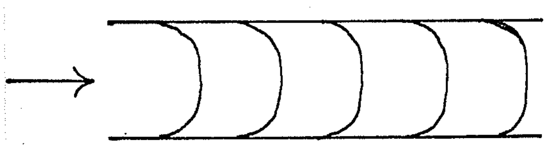


FIGURE 3c

RIB OR RIPPLE MARKS ON FRACTURE SURFACE

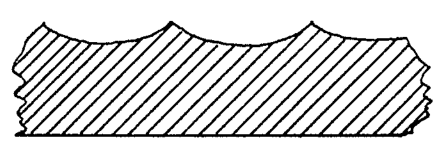


FIGURE 3d

CROSS SECTION OF FRACTURE SURFACE RIPPLE MARKS

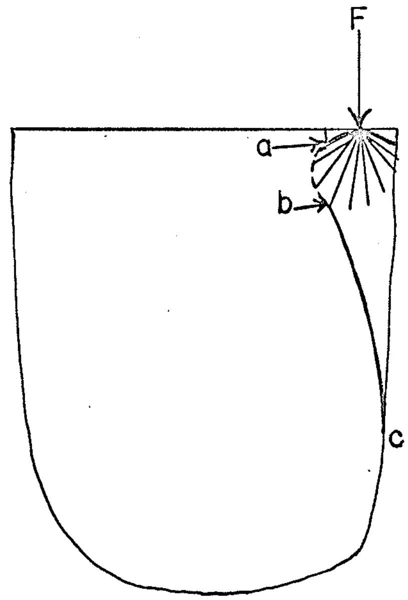


FIGURE 4 a

PROPAGATION OF SURFACE CRACK ALONG STRESS LINES a-b OF SPHERICAL WAVE AND b-c OF SHEAR STRESS TRAJECTORY RESULTING FROM FORCE F

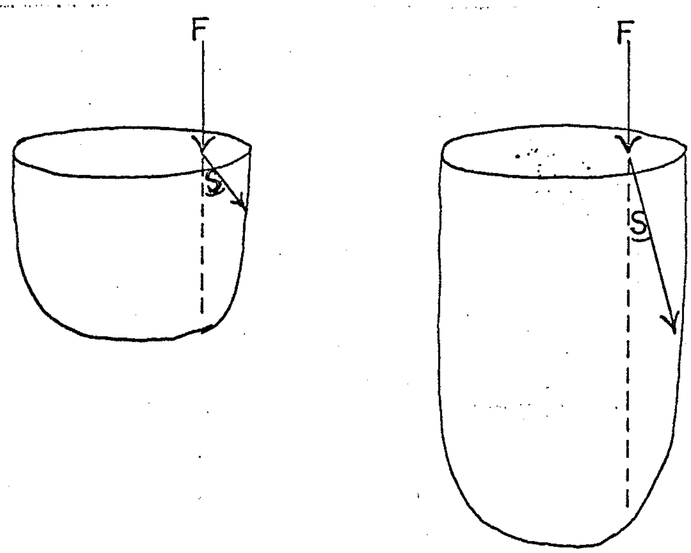


FIGURE 4 b

DIFFERENCES IN ANGLE OF SHEAR STRESS DUE TO DIFFERENCES IN LENGTH: WIDTH RATIO OF TWO ISOTROPIC BODIES

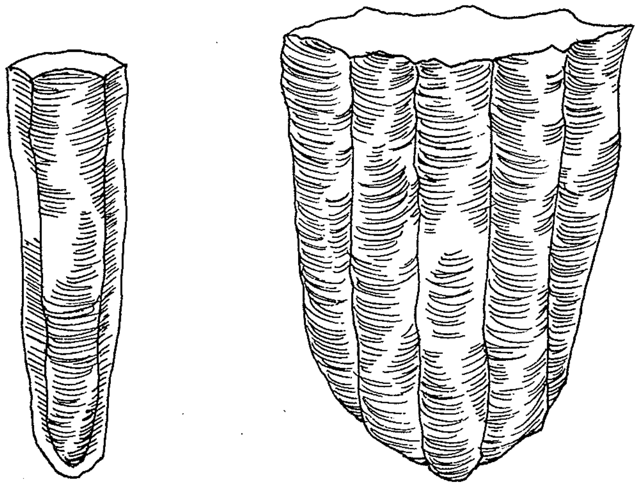


FIGURE 5a

PRISMATIC BLADE AND CORE

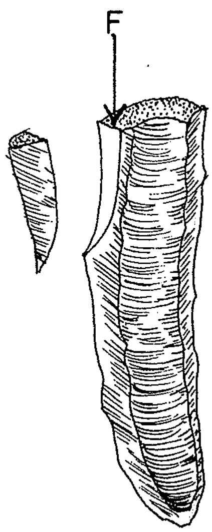


FIGURE 5b

TECHNIQUE OF BURIN PREPARATION

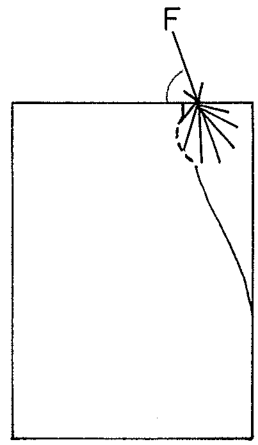


FIGURE 6a
FREE FLAKING

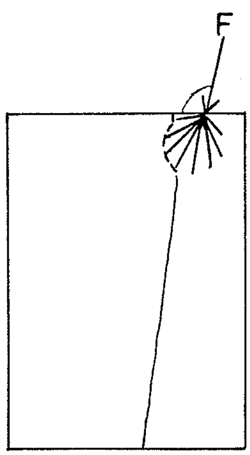


FIGURE 6b
RESOLVED FLAKING

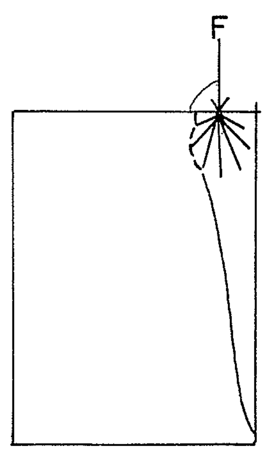
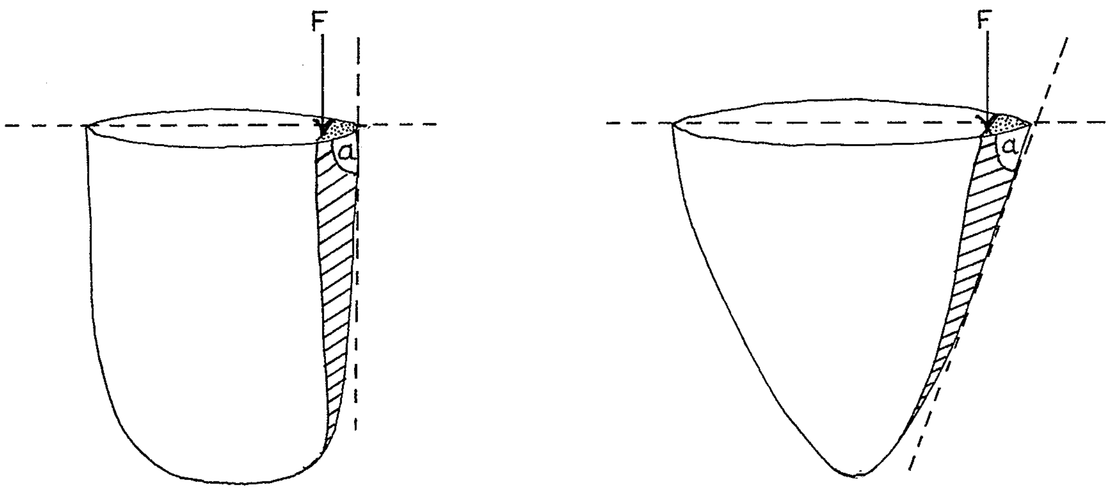


FIGURE 6c
FLAT FLAKING



CYLINDRICAL CORE
a

CONICAL CORE
b

FIGURE 7

ESTIMATION OF CORE SHAPE BY OBSERVATION OF ANGLE (α) SUBTENDED BY STRIKING PLATFORM AND OUTER SIDE OF DETACHED FLAKE, TOGETHER WITH GENERAL FLAKE MORPHOLOGY

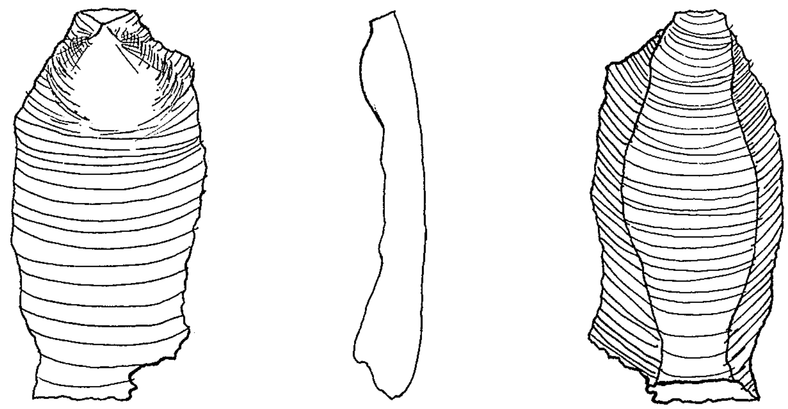


FIGURE 8a

VIEWS OF INNER FACE, LONGITUDINAL CROSS-SECTION AND OUTER SIDE OF A BLADE-LIKE FLAKE FROM EL INGA COLLECTION

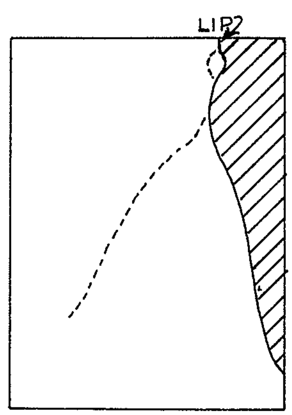


FIGURE 8b

EXPLANATION OF LIP ON BATON PERCUSSION FLAKE AS RESULTING FROM FORKED FRACTURE (SEE FIGURE 3b)

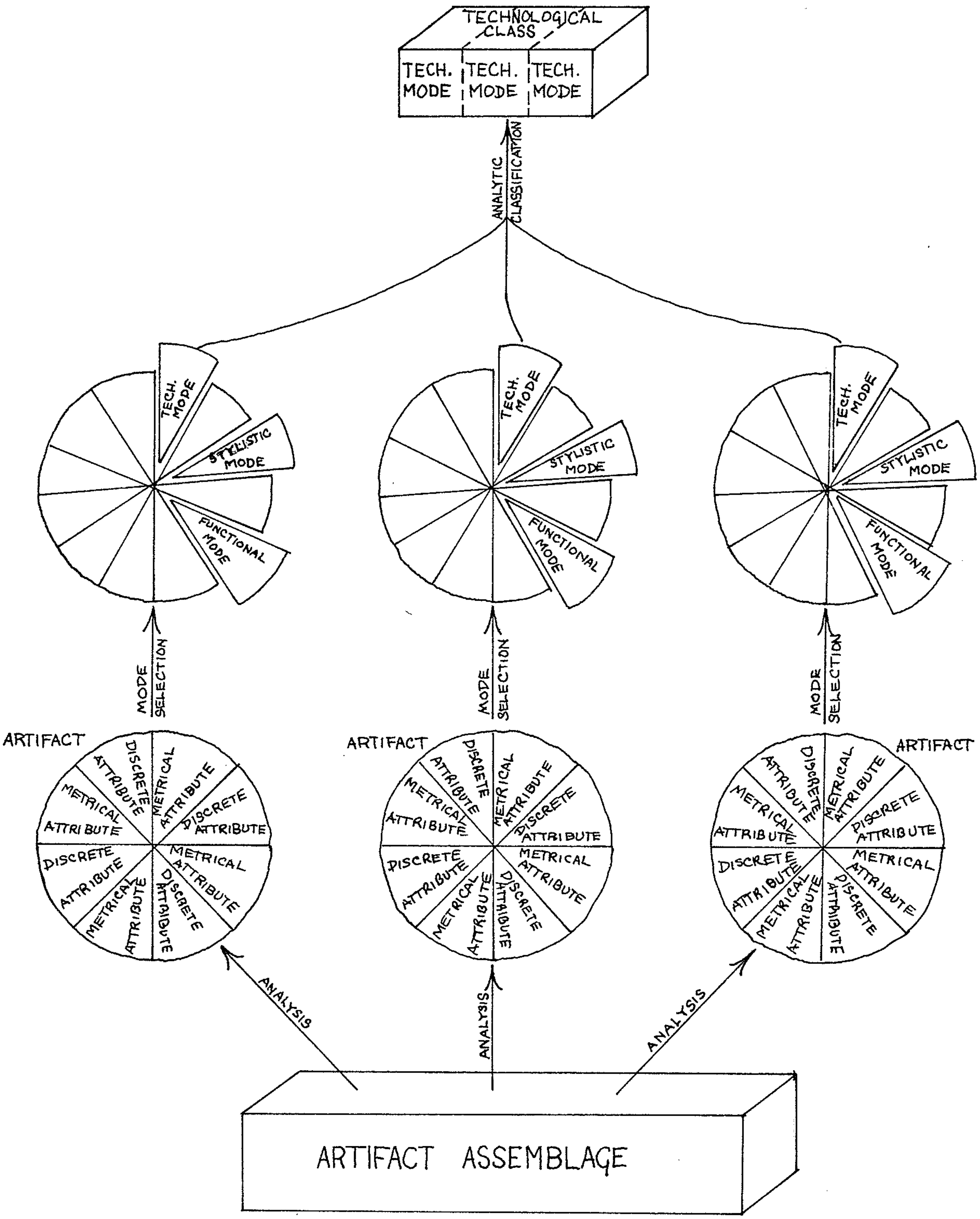


FIGURE 9

ANALYTICAL CLASSIFICATION

"Some Discrete Attributes of Blade-Like Flakes"

A.	Ripple Marks:	(1) Pronounced and frequent (2) Weak and low frequency (3) Absent
B.	Grooved Shatter Lines:	(1) Present (2) Absent
C.	Platform I: (shape and size)	(1) Complete and undamaged (2) Pointed (or pyramidal) and small (3) Relatively complete and bruised
D.	Platform II: (preparation)	(1) Prepared (2) Unprepared (3) Indeterminate
E.	Curvature:	(1) None (2) Slight (3) Moderate to pronounced (4) Indeterminate
F.	Bulb:	(1) Very prominent (2) Prominent (3) Flat

Figure 10.