OBSIDIAN AND ITS SIGNIFICANCE TO NORTH AMERICAN ARCHAEOLOGY

A Thesis
Presented to
the Faculty of the Department of Anthropology
University of Manitoba

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

by
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October 1972

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CHAPTER I

INTRODUCTION AND THE NATURE OF OBSIDIAN

I. INTRODUCTION

I was introduced to obsidian during the summer of 1969 as a laboratory assistant to Dr. W.J. Mayer-Oakes in the Laboratory of Anthropology at the University of Manitoba. I was assigned the task of analyzing literally thousands of obsidian artifacts from El Inga and San Jose, Ecuador. During the summer I became familiarized with the obsidian hydration dating technique as the laboratory possessed a complete hydration set-up. I became enthusiastic about the possibility of using obsidian in several kinds of archaeological analysis. The present paper is an outgrowth of that enthusiasm. I felt that there was a genuine need for a synthesis of the obsidian research performed to date to bring attention to the benefits to archaeology that obsidian has to offer.

Serious consideration of obsidian by archaeologists began a mere fifteen years ago. It is only recently that obsidian research has gained the level of sophistication necessary for it to be recognized as a valuable aid to the profession. There is a great deal which archaeologists can learn by studying obsidian artifacts. In the following chapters, I propose to outline the role that obsidian does play now and can play potentially. The major part of the material reviewed in this paper was gleaned from the archaeological literature, although I have included data from research in which I was directly involved. The following chapters will deal with, in order: the development and method of the obsidian hydration dating technique, the techniques of obsidian source determination, obsidian sources, distribution and possible trade areas and finally with obsidian technology, experimental archaeology and a comparison of flaking techniques.

Obsidian is found in all of the volcanic regions of the earth, from Alaska to Crete, from Peru to Japan. For millenia, obsidian has provided Man with a very efficient tool--the sharp edge. Because it is relatively easy to fashion into a variety of artifacts, it came to be prized. Obsidian was also admired for its aesthetic qualities, in fact, it became so valuable that it was distributed over great distances.

Obsidian was a valued commodity in many prehistoric societies. As those societies faded out of existence, all that was left behind was part of their material culture, their hardware, which included obsidian. Archaeologists study this hardware or artifacts hoping to gain insights about the societies which produced them. Artifacts outline behaviour patterns and are comparable to congealed human actions (Clark 1968:19). According to Binford (1968) the archaeologist takes these congealed behaviour patterns and attempts to achieve three goals with them: culture history, culture process and cultural reconstruction.

Obsidian is admirably suited to the fulfillment of these goals. The obsidian hydration dating technique provides a reliable method of deriving absolute dates thus achieving the goal of culture history. The various techniques of source determination have made it possible to observe the distribution of obsidian through space, i.e. prehistoric trade patterns, thus achieving the goal of culture process. Because of its unique fracturing properties, obsidian can be used to analyze the fundamental differences between various lithic technologies thus achieving the third goal of cultural reconstruction.

II. THE NATURE OF OBSIDIAN

Obsidian is a natural glass which formed as the result of the slow cooling of lava at great depths and under such pressure that the escape of the steam and other gases was greatly impeded (Flett 1954).

Chemical Properties

Obsidian is largely composed of feldspar and quartz and has, therefore, a very high percentage of silica. The materials are basically the same as those which form granite but the cooling process did not permit crystalization. Obsidian is acidic or ryholitic. This fact and its low water content (less than 1% by volume) helps distinguish it from the dark, semi-opaque forms of the basic igneous rocks known as trachytic glasses.

The major chemical constituents of obsidian vary only slightly from region to region (Table I). Besides these major constituents, obsidian contains numerous trace elements such as: barium, strontium, zirconium, yttrium, niobium, lanthanum, rubidium, lithium, molybdenum, gallium, vanadium, lead, tin, calcium, iron, magnesium, scandium, cesium, chromium, nickel, cobalt, copper, sodium, manganese and antimony.

Physical Properties

The most common observable color in obsidian is black but it may also be grey, red, brown, green or a blend of colors. The color has

TABLE I

COMPOSITION OF OBSIDIAN

	Yellowstone %	Iceland %	Mexico %
SiO_2	74.70	75.28	75.23
Al_2O_3	13.72	10.22	12.36
Fe_2O_3	1.01	4.24	0.96
FeO	0.62	---	1.24
MgO	0.14	0.25	0.01
CaO	0.78	1.81	1.00
Na_2O	3.90	5.53	4.00
K_2O	4.02	2.44	4.62
H_2O	0.62	0.23	0.73

(After Flett 1954: 676)

been attributed to microscopic inclusions of magnetite in various states of oxidization but under a microscope, obsidian is colorless. The cryptocrystalline structure of obsidian caused by the cooling process makes it extremely homogeneous and contributes to its glassy lustre, brittleness, and conchoidal fracture. Obsidian measures about 6 on the Moh scale of hardness, placing it between slate and chalcedony. Its specific gravity is between 2.35 and 2.5 (Semenov 1964:34) and its density is between 2.25 and 2.5 (Speth 1972:52).

Within recent years, researchers have discovered that the outer surface of obsidian absorbs atmospheric water (Ross and Smith 1955; Friedman 1958). The index of refraction is higher in this hydrated layer, thus making it visible under a microscope. This discovery made the subsequent development of the obsidian hydration dating technique possible.

Obsidian appears to have the properties of a solid, yet it behaves in the manner of heavy liquid (Crabtree 1968). When force is applied to obsidian, frictional planes of molecular movement and wave motion create ripples and undulations on the surface as well as unexplainable microscopic fissures (*Ibid*.). These manifestations of force are indelibly recorded on obsidian artifacts and may provide the key to analyzing prehistoric lithic techniques.

CHAPTER II

THE OBSIDIAN HYDRATION DATING TECHNIQUE

A freshly exposed surface of obsidian will constantly take up water from the atmosphere to form a highly saturated surface layer. This hydrated layer has a different density and index of refraction than does the rest of the obsidian. A thin-section of the obsidian cut at right angles to the surface can easily be prepared and with the aid of a microscope, the hydrated layer can be measured (Fig. 1).

Prehistoric artisans, in the process of shaping obsidian artifacts, exposed fresh (non-hydrated) surfaces. The finished artifacts were then buried as grave or ceremonial offerings, discarded or lost in the refuse of a habitation site. If the radiocarbon or dendrochronological age of one of these obsidian artifacts is known, then the thickness of any hydrated layer can be measured and by correlation with the known age, the rate of hydration can be reliably established.

With the hydration rate determined as accurately as possible, the most useful applications of obsidian dating in a region can be outlined as follows (Meighan 1968: 1073-74):

1. direct determination of age.
2. range and intensity of occupation period.
3. an independent check of other dating techniques.
4. time range of individual artifact types.

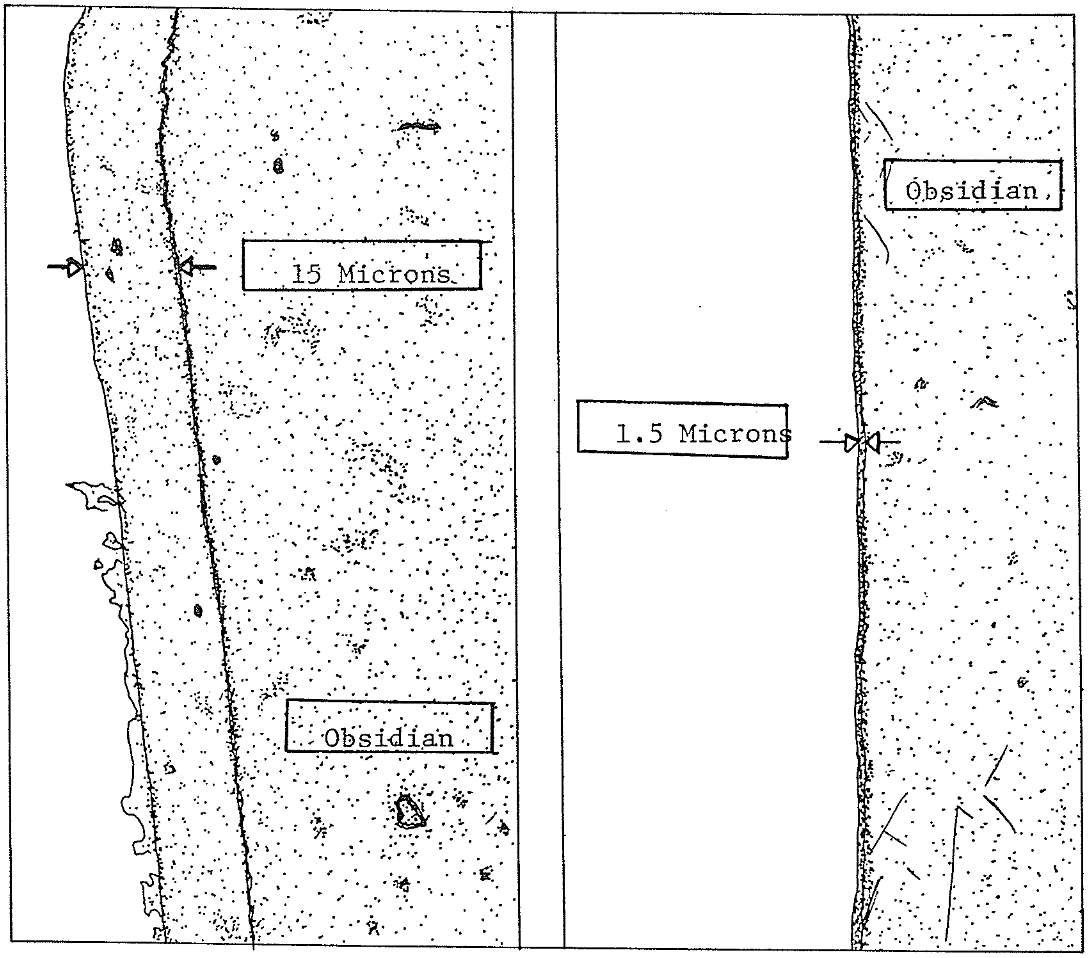


Figure 1. Obsidian Hydration Rims

(after Friedman and Smith 1960)

I. THE DEVELOPMENT OF HYDRATION RESEARCH

In the course of a study of volcanic glasses, C.S. Ross and R.L. Smith (1955: 1071), observed that the naturally formed surfaces on obsidians that they examined had undergone a chemical and physical change which they called hydration. The water taken up by the obsidian surface had caused an increase in density in this outer layer slightly raising the index of refraction of the hydrated layer making it visible under magnification.

Irving Friedman and Smith combined forces in 1958 and attempted to demonstrate that the hydration process is continuous and that it occurs at a constant rate. Clifford Evans and Betty Meggers supplied the archaeological specimens from Mesoamerica for Friedman and Smith to work on. It was during this research that the hydration of obsidian came to be regarded as a possible absolute dating technique. The absolute date could be expressed in the same way as radiocarbon date; as absolute calendrical date expressed in years BP (before present).

Early in their research, Friedman and Smith became aware that hydration rates from several areas in the world were not uniform. They speculated that the major factor that influenced this variance was temperature.

Because each of the submitted specimens had already been assigned a calendrical date by one of the other dating methods, Friedman and Smith could compare the assigned date against the thickness of the hydration rim expressed in microns. After a few reference dates were established for each region, a tentative rate for a given climatic

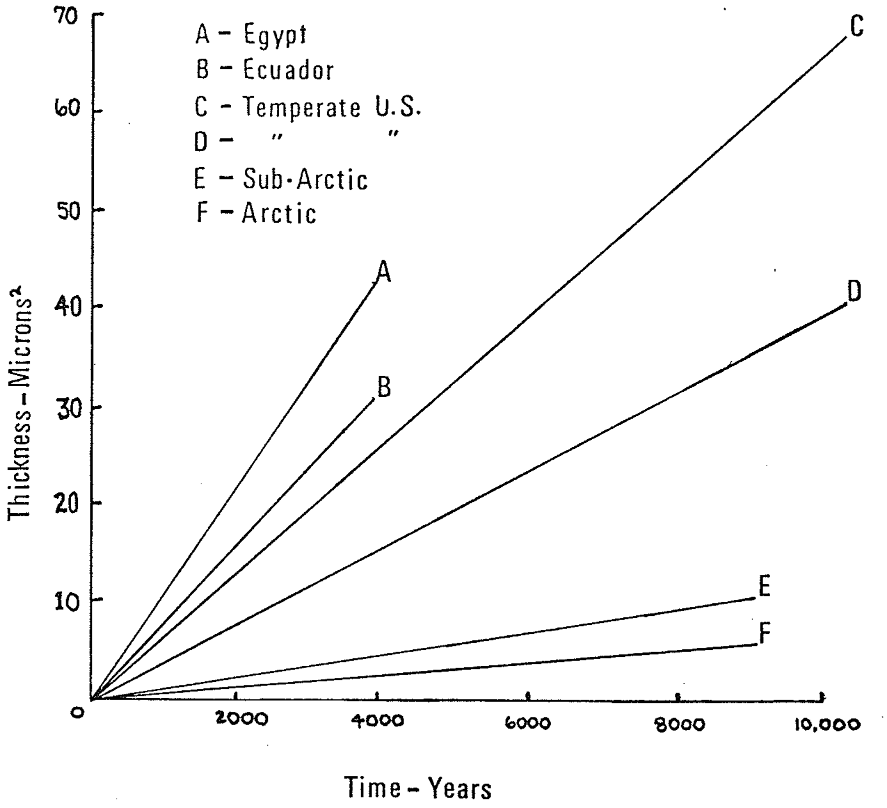


Fig 2 Hydration Rates for Several Climatic Zones

(after Friedman and Smith 1960)

zone could be computed (Fig. 2). By 1960, they felt they had enough results to publish. In the same year, Meggers and Evans did an archaeological evaluation of the technique. They tended to favor closer correspondence of hydration dates with those obtained from radiocarbon dating (p. 523-37).

In 1959, Donovan Clark, a PhD. candidate at Stanford University began work on obsidian hydration. He did his research in Central California seeking to derive a regional hydration rate and to refine the existing techniques. This work culminated in his doctoral dissertation (1961). He took the same approach as Friedman and Smith, that obsidian hydration dating is a technique for obtaining absolute dates. In the course of his work he collected obsidian artifacts from sites in one region of California. By plotting associated radiocarbon dates against rim thickness, he was able to calculate the hydration rate. He then undertook a statistical evaluation of the technique arriving at the conclusion that there is high reliability with regard to the association of hydration values with archaeological estimates.

Clark and Evans became associated in 1960. They outlined what seems to be, in retrospect, a rather lofty goal, proposing to:

1. determine the nature of all possible factors which control or modify rates of hydration.

2. classify obsidian artifacts and obsidian rock from natural sources on a world wide basis according to differences in composition and texture.

3. establish definitive regional rates of hydration from which absolute dating can be derived.

4. standardize the techniques of the method for routine use in the fields of archaeology and geochronology.

The results were published by the Smithsonian in 1965 in a form which came considerably short of the original goal, in fact, not achieving one of their proposals.

The first archaeological hydration laboratory in North America was started in 1963 at UCLA. Clark operated this laboratory and when it went into full operation in 1964, Joseph Michels began dating the 453 artifacts which were used as data for his dissertation. Michels attempted to "explore and illustrate the uniqueness and versatility of this dating technique in its application to archaeological material, rather than directing attention to validating its capacity for rendering absolute calendrical dates along the lines of radiocarbon dating" (1965: 15-16).

Since 1965, there seems to have been very little alteration of the techniques outlined by Michels. The laboratories which began operation after 1965, such as at Michigan, Pennsylvania and Manitoba, have concentrated on the dating of artifacts. Meanwhile, basic research, primarily at UCLA, has shifted toward obsidian chemistry in an attempt to pinpoint obsidian sources and to discover the factors which affect hydration rates.

II. THE HYDRATION TECHNIQUE

The technique for selecting, preparing and dating specimens was originally conceived of by Friedman and Smith (1960). It was further developed by Clark and Michels at the UCLA obsidian hydration laboratory and has been adopted in that form by other hydration laboratories.

At the University of Manitoba's Laboratory of Anthropology, Dr. W.J. Mayer-Oakes established a hydration lab which operated from 1967 to 1970. He was seeking dates for some of the material he had recovered in Highland Ecuador. The procedures utilized at the Manitoba lab were essentially the same as those outlined by Clark (1961) and Michels (1965). It was during this period, while working with Mayer-Oakes, that I became familiar with the obsidian hydration technique.

The complete list of equipment and material essential for hydration dating is included in Appendix A of Michels' dissertation (pp. 211-14) and is reproduced here in Appendix I.

Complete instructions for preparing and mounting thin-sections are included in Appendix II so only certain highlights are noted here. The specimens should be numbered and segregated into separate envelopes to prevent further accidental retouch the specimens should also be numbered so that the wedges and specimens can be later matched up with a minimum of trouble.

Once the wedges are mounted, an individual has to determine his own calibration factor before actually starting to measure the width of hydration rims. This will compensate for any discrepancy between observed thickness and the actual thickness of the hydration rim. A calibration factor must be determined for each ocular objective combination. Michels suggest frequent recalibration. This procedure is outlined on pages 232-233 of Michels' dissertation and is included as

Appendix III.

The microscope procedure for measuring the width of the rims is outlined on pages 16-19 of Clark's dissertation and is included here as my Appendix IV. Michels has added one major modification to this procedure by substituting polarized light for ordinary light. This brings the hydration rim into maximum clarity.

III. FACTORS AFFECTING HYDRATION RATES

Continuing research into hydration dating has concentrated on the factors affecting rates of hydration. The existing hydration equations used to describe the process take into account only two independent variables, time and temperature. The basic equation, describing the hydration phenomena, appears to be diffusion law: $D = kt^n$, where D equals the thickness of the hydration layer in microns, k is a constant, t is the time in years and n is a variable factor relating to temperature (J. Ericson and R. Berger 1971: 1). The temperature coefficient of obsidian is probably the largest variable and it does seem the easiest one to assess and correct for (Friedman 1969:69).

Some of the other factors which were thought to affect the rate of hydration are relative humidity, chemical composition and such mechanical factors as burning or abrasion. Friedman and Smith (1960) and Ericson and Berger (1971) have established that relative humidity has little or no affect on the hydration rate. The mechanical factors, burning and abrasion, do not affect the rate per se, they simply destroy the hydration layer making it difficult or impossible to measure it. Friedman and his colleagues contend that the chemical composition does have a decided affect on rates. Likewise, Ericson and Berger (1972) have concluded that the ratios of important chemical constituents such as silicon to oxygen have decided affects on the rates. They have also discovered that the specific volume or density may be a factor which influences the hydration rate.

The factor which most directly affects the rate of hydration seems to be temperature. Given the variation of temperature geographically, and through time, it is important for analysts to establish regional and temporal temperature coefficients. To this end, climatological and paleoclimatological evidence has been gathered so that the temperature factor in the hydration formula is under control.

One factor which indirectly affects obsidian hydration results is cultural in nature. This is the mixing of archaeological strata by intrusion or artifact re-use. Michels contends that the technique can be used to test stratigraphy and artifact re-use (1969: 15-22). Thus, he believes that hydration dating can be used to straighten out the confusion of disturbed stratigraphy.

Present research by Ericson and Berger under the guidance of Clement Meighan at UCLA is an attempt to correlate the chemical and physical properties of obsidian with natural and induced hydration data. The results of this research should conclusively pinpoint all of the important factors affecting hydration rates.

IV. EVALUATING THE TECHNIQUE

As was pointed out above, Meggers and Evans (1960) did an extensive evaluation of the obsidian hydration dating technique. They concluded that the method had "considerable promise if it is used with appropriate care and understanding of its present limitations". They felt, with justification, that there was a large amount of uncertainty about the geographical rates of hydration. They also voiced fears about the inability of the hydration technique to deal with the problems of mixing and re-use. Since their study in 1960, researchers such as Friedman and Smith, Clark, Michels, Meighan and Ericson and Berger, have come a long way in overcoming the problems which face the hydration technique. Reliable and accurate regional rates have been established. The Technique has been very nearly perfected. Thousands of dating operations have been carried out, in fact, the laboratories at UCLA and Michigan are operating on a commercial basis.

In conclusion then, the obsidian hydration dating technique is a very reliable method of doing both absolute and relative dating. There are a number of problems which are inherent in the technique but which are being significantly reduced by continuing research. The technique itself is both rapid and inexpensive, a sample costing only a third of what a radiocarbon determination costs. The results have been totally consistent with those obtained by established dating methods. There is a growing confidence in the technique as its problems are solved and as archaeologists realize that the limitations are quite minor. The obsidian hydration dating technique is a significant addition to archaeological technique and will be widely used in future archaeological programs. Closely allied with the research into the factors affecting hydration rates is the program of source determination which is being carried out in several parts of the world. This research and the nature of obsidian sources is dealt with in the following chapter.

CHAPTER III

OBSIDIAN SOURCE DETERMINATION

Artifacts of obsidian have been found in archaeological sites which are far from any known source of the material. If such a material is used by a community does not occur locally, one must conclude that it was imported and the possibility exists that it was obtained through trade with another population. This prospect intrigues investigators who are attempting to locate the sources of obsidian artifacts, i.e. to reconstruct the trade routes in man's economic and social prehistory. The implications of such investigations are obvious. Many questions about the diffusion of cultural traits can be answered and insights into the nature of prehistoric interaction can be gained. The determination of specific sources is based on the premise that the chemical composition of an obsidian from each source is distinctive enough to be distinguished from other sources. Thus, if the chemical composition of an obsidian matches closely the chemical composition from a particular source, it can be assumed that the material from which the artifact was created was originally derived from that source.

I. TECHNIQUES OF ANALYSIS

There are numerous trace elements present in obsidian which are found in various proportions. As each source is assumed to possess a unique ratio of trace elements, the techniques of analysis that have been developed are mainly concerned with the detection and measurement of trace elements.

Physical appearance has limited applicability in differentiating obsidians, although such factors as color in transmitted light, fracture, translucency with internal structure and lustre may be useful for preliminary analysis (Cann and Renfrew 1964: 114).

Chemical analysis has been used to determine the proportions of the major constituents of obsidian. The method has been inconclusive as meaningful differences between areas (sources) with proportions of elements falling in very narrow ranges are difficult to determine.

The most popular techniques for identifying the trace elements in obsidian are: optical emission spectroscopy, neutron activation analysis, X-ray flourescence and gamma ray spectrometry.

Optical Emission Spectrometry

This technique was used with great success by Dixon, Cann and Renfrew (1968) in their study of Neolithic trade routes in the Mediterranean. The technique is based on the fact that different elements emit different wave lengths. In addition, quantitative analysis of the elements present can be made because different concentrations of an element will emit spectra of different intensities, and those spectra lines can be compared with samples of known concentration. As many as twenty elements can be determined during the course of experimentation within the range of 0.001% to 10% by weight. The heavier elements are more easily calculated in minute amounts; except for lithium, elements of a smaller atomic number, smaller than magnesium, are generally not effectively measured.

A small sample of obsidian is ground and mixed with an equal volume of carbon. It is volatized between two carbon electrodes. The emission lines are passed through a prism and reflected on a photographic plate (Fig. 3). The wave lengths that produce these lines are calculated in Angstrom units (Angstrom unit A = 1/100,000 cm.). The blackened lines on the photograph are then evaluated by a photoelectric device called a microphotometer.

Cann and Renfrew (1964) confined their analysis to sixteen trace elements in proportions of 0.001% to 1%. They used a 60 milligram sample and quantitatively measured barium, strontium, zirconium, yttrium, niobium, lanthanum, lithium, molybdenum, gallium, lead, rubidium, vanadium, tin, calcium, iron and manganese. The samples were divided into groups: the major ones on the basis of amounts of zirconium and barium and the sub-groups were distinguished according to amounts of niobium and yttrium. Ranges in composition were found among sub-groups but the researchers felt that the ranges between sub-groups were more important than the ranges within particular sub-groups. On the basis of relative quantities of elements, artifacts were associated with particular obsidian sources. Thus, they have postulated on the basis of these relationships, source areas and trade routes in the region of the eastern Mediterranean.

Neutron Activation Analysis and Gamma Ray Spectrometry

The neutron activation technique is used by North American obsidian researchers such as J.B. Griffin, A.A. Gordus and G.A. Wright of the University of Michigan, As with optical emission spectrography, this technique quantitatively measures trace elements but does not involve any destruction of the material.

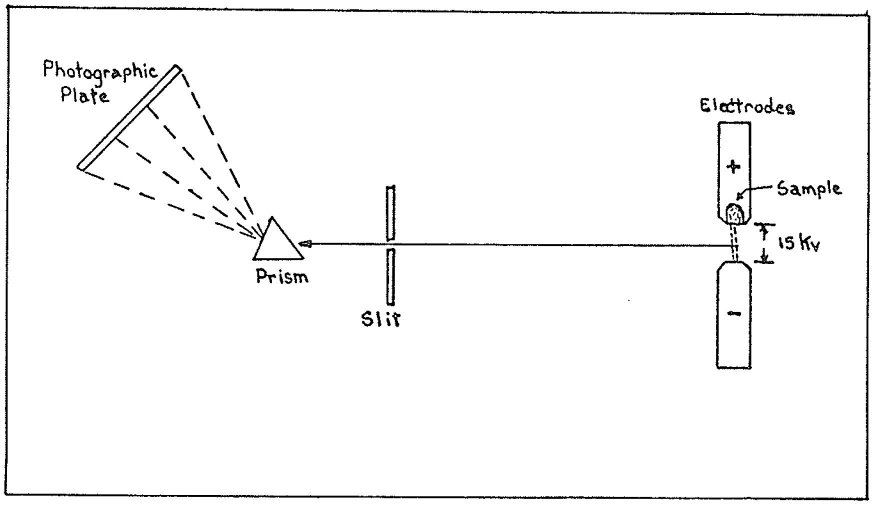


Figure 3. Optical Emission Spectrography

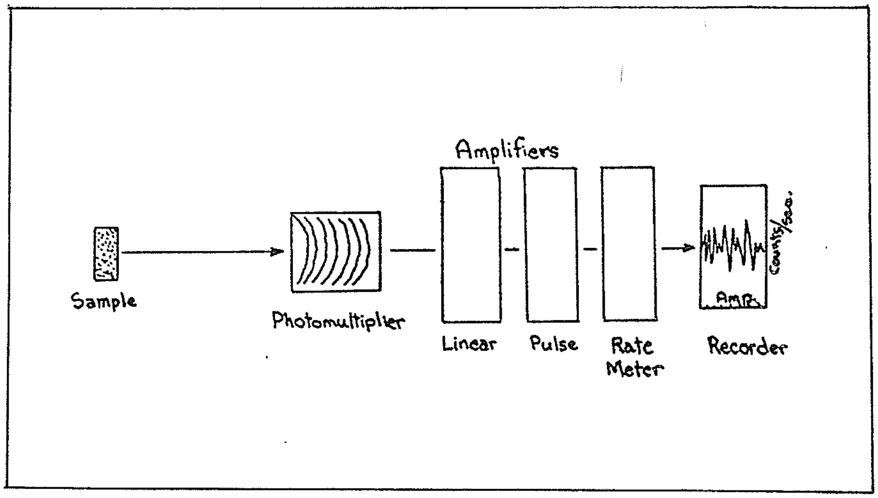


Figure 4. Neutron Activation Analysis

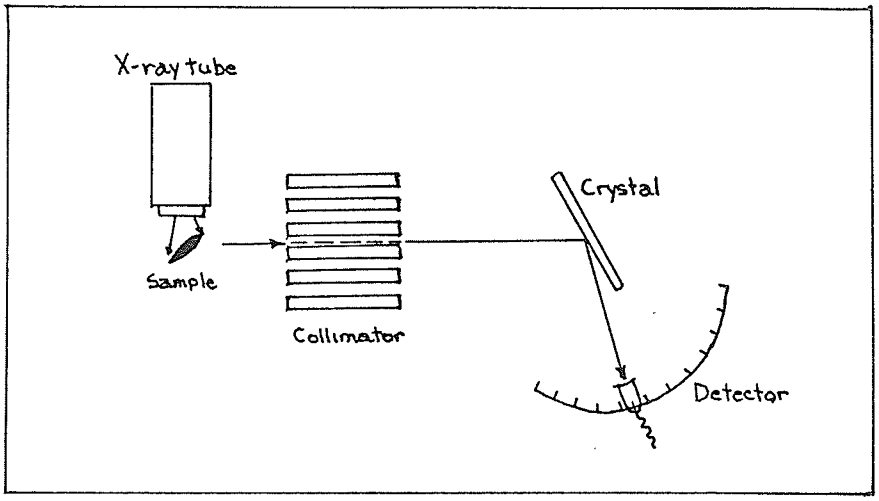


Figure 5. X-Ray Flourescent Spectrometry (after Aitken)

Neutron activation analysis (Aitken 1960: 166-69); Gordus et al 1968:383-84) involves bombarding a sample with neutrons. After a sample has been bombarded, the various elements "decay" or give off the extra neutron in the nucleus, either forming the stable isotopic form or another element. Each of the original elements gives off a characteristic amount of gamma ray energy as it decays. The intensity and number of gamma rays given off is measured by a gamma ray scintillation spectrometer.

When the emitted gamma ray strikes the scintillation crystal, a pulse of light with an intensity characteristic of the element is emitted and picked up by the light sensitive photomultiplier which gives the light impulse amplitude. The pulse analyzer transmits amplitudes within set limits to the ratemeter. A spectrum of original gamma ray energies is plotted in such a way that the position of the peak tells what elements are present and the heights of the peaks indicate the concentration (Fig. 4). Because of the penetrating powers of the neutrons and gamma rays, the entire sample will be analyzed rather than the mere surface.

The Michigan researchers (Gordus et al 1967: 34) feel that the most important factors in neutron activation analysis are speed and sensitivity. The other important factor is that relatively large samples (several cubic inches) are analyzed because of the deep penetration and high sensitivity. Portable neutron activation apparatus is now available, making possible the analysis of material right in the field.

X-Ray Flourescent Spectrometry

The technique of X-ray flourescence (Fig. 5) has been applied to the analysis of material for a number of years (Hall 1960: 29-35; Aitken

1961: 161-69). Glass and ceramic artifacts are often analyzed by this method to verify their authenticity. The technique involves the irradiation of the artifact with X-rays of sufficient intensity until the various elements emit X-rays themselves. These X-rays are sorted by means of a crystal, analogous to the sorting of visible light by means of a diffraction grating, and are then evaluated electronically (Weaver and Stross 1965:90; Parks and Tieh 1966: 289-90). The latter researchers measure the ratio of strontium to rubidium to characterize sources. This technique has the advantage of being rapid and sensitive. Consequently, it is an ideal method for examining a great number of samples (Aitken 1961:165). Unfortunately, it is not sensitive enough to differentiate between obsidians of similar composition.

Fission Track Dating

Obsidian contains small traces of uranium (U 238) which decays at a slow, constant rate. By measuring the rate of decay, the age of the obsidian can be determined. Some obsidians formed from the same parent material may have been formed thousands or millions of years apart. The technique can potentially distinguish between sources that have very similar trace element composition by determining their times of formation.

The technique (Brill 1964:51-57; Fliescher, et al 1969: 58-61) is based on the fact that as uranium decays it releases energy into the surrounding obsidian creating microscopic "etch pits". Hydroflouric acid is used to treat a freshly fractured surface. This makes the etch pits visible. The number of pits is compared either with the uranium content as determined by chemical analysis, or by a second count of etch pits as the result of induced fission by bombarding a fresh surface with a known dosage of thermal neutrons. The sample is again treated with hydroflouric acid and this new group of etch pits is counted.

The major disadvantage of this technique is that there is a very high error factor for recent samples due to the long half-life of uranium. Recently formed sources will have an error factor as high as ± 25% (Syms 1966:12). Exposure to high temperatures will cause the track to fade out in a few decades. In some types of obsidian, the etch pits are difficult to discern due to such factors as extreme clarity, gas bubbles and impurities (Ibid.). This technique has limited applicability in correlating sources and artifacts but it does provide a rapid and accurate method of differentiating flows on the basis of their time of formation.

Of the techniques described above, optical emission spectroscopy and neutron activation are the two which have been most widely applied and which give the most satisfactory results. They have enabled researchers to positively identify most of the major obsidian flows in the world. It is now possible, in many cases, to associate artifact obsidian with its parent flow. The possibility of being able to assign a source for obsidian in archaeological sites has many implications for future work, especially where there are varied sources for the material (Frison, et al: 1968:216). The following sections of this chapter will deal with some of the major sources of obsidian in North America, some of the larger finds of obsidian artifacts and some speculation on trade patterns.

II. MAJOR SOURCES OF OBSIDIAN IN NORTH AMERICA

There are relatively few areas in North America where flows or deposits of obsidian occur (Fig. 6). These flows are found in the mountainous areas of Western North America where there has been recent (within a million years) volcanic activity. Fragments of obsidian are often found in deposits created by stream action or other erosive processes. Obsidian from flows and from secondary deposits was an important source of raw material for prehistoric man. The most important areas in North America where obsidian is found are Alaska, Northwest United States, Northern California and New Mexico, Central Mexico and Highland Guatemala.

Alaska

Patton and Miller (1970) have discovered the probable bedrock source of the artifact obsidian found in Northwestern Alaska at such sites as Cape Denbeigh (Giddings 1951) and Onion Portage (Griffin, et al 1969). The deposits are located along the Koyokuk River Valley in Central Alaska. The sodium-manganese ratio as determined by neutron activation analysis was used to characterize the sources.

Northwestern United States

In the Northwestern United States, there are about forty-five known sources of obsidian (Wright, et al 1969: 27). Of this number, at least sixteen are to be found in Yellowstone Park in Wyoming, alone. Some of the more significant finds in the Northwest are: Obsidian

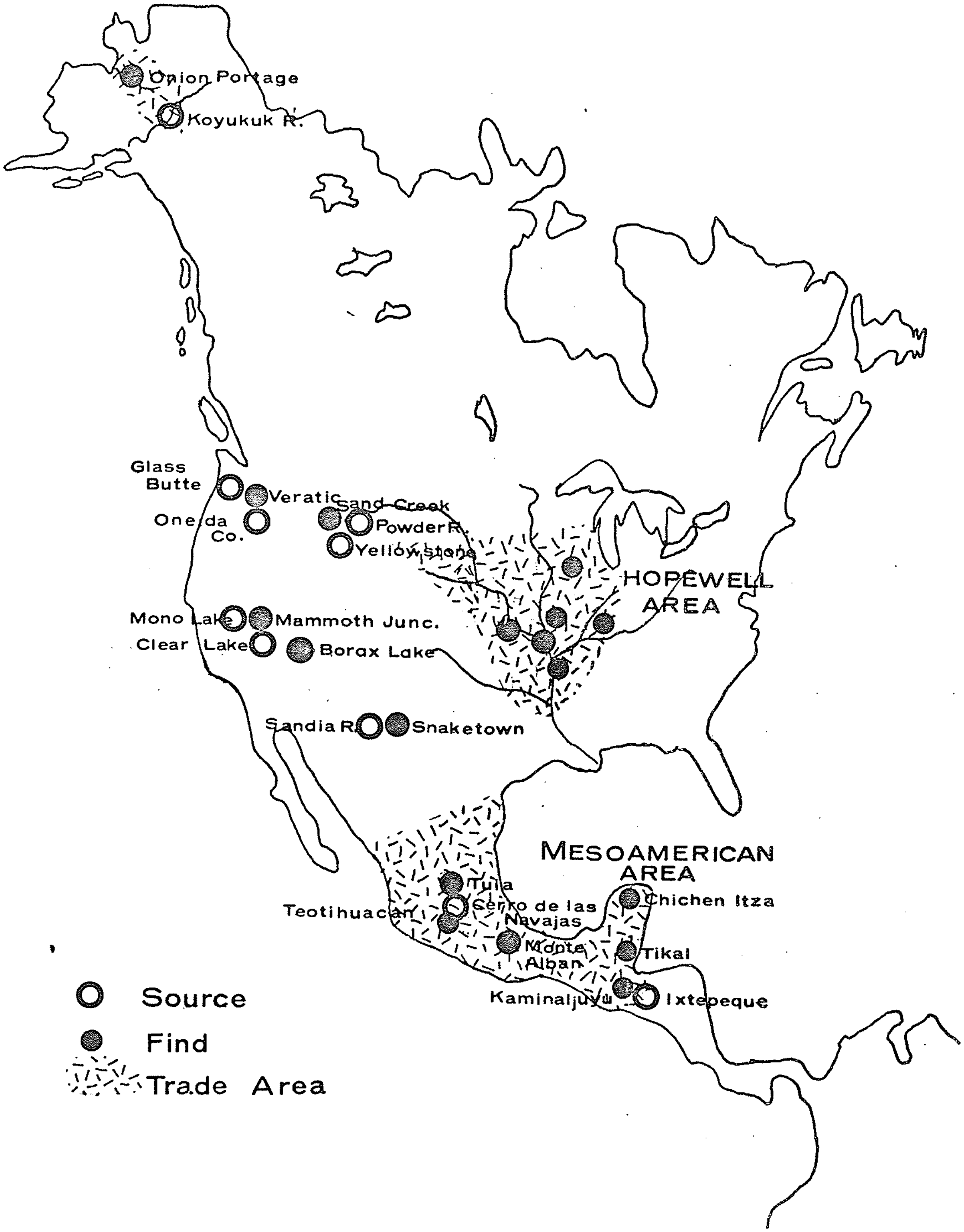


Fig.6 Obsidian Sources, Major Finds and Trade Areas

Cliff, Wyoming (Griffin, et al 1969); Powder River, Montana (Frison, et al 1968); Oneida County, Idaho (Ibid.); Crater Lake and Glass Butte, Oregon and Millard County, Utah (Wright, et al 1969).

Northern California and Southwest United States

Considerable quantities of good quality obsidian are found in Northern California at Glass Mountain, Clear Lake and Mono Lake (Parks and Tieh 1966). The most important sources in Nevada have been identified as Montgomery Pass and Massacre Lake (Stevenson, et al 1971). The most notable of the sources in New Mexico is at Sandia River (Ibid.).

Mesoamerica

Mesoamerica has surprisingly few sources of good quality obsidian. The major regions which were exploited for their obsidian deposits are the Sierra Region of North Central Mexico and the Guatemalan Highlands. The most important quarries in Northern Mexico are Sierra de la Venta, Jalisco; Sierra de San Andres, Michoacan and Cerro de las Navajas, Hildago (Heizer, Williams and Graham 1965). Pachuca and Otumba, near Mexico City, were also important sources (Stevenson, et al 1971).

In Guatemala, the area around Ixtepeque volcano was an important source for the entire region (Op.cit.). This source is the largest in Mesoamerica and is probably the largest in the world (Heizer, et al 1965). A source at El Chayal was very important during Archaic times but does not seem to have been exploited during Classic or Pre-Classic times (Coe and Flannery 1964).

III. DISTRIBUTION OF OBSIDIAN AND POSSIBLE TRADE AREAS

Obsidian artifacts have been found scattered in sites from a number of areas in North America (Fig. 6). Archaeologists do not concentrate on the rare pieces of obsidian whose presence cannot be accounted for. Rather, they are interested in those sites where obsidian is a widespread lithic material. Of course, they are most interested in those sites where obsidian is common, but also exotic to the area. Thus, when substantial amounts of any exotic material, including obsidian, appear in sites the archaeologist can infer that some sort of interaction is taking place. He seeks to understand the nature of this interaction hoping to gain insights into cultural processes. Sites containing obsidian are usually found close to sources but in a few cases the distance between site and source involves several hundred miles. Areas where sites containing obsidian artifacts have been found are Alaska, Northwest United States, California and the Southwest, the Midwest and Mesoamerica.

Alaska

The obsidian from the multi-component sites in Western Alaska at Cape Denbeigh and Onion Portage has been positively identified as coming from the Koyukuk River Valley in Central Alaska, several hundred miles away (Patton and Miller 1970). In the stratified Onion Portage site, the abundance or lack of obsidian in various cultural layers may reflect the ebb and flow of coastal-oriented and inland-oriented cultures along the Kobuk Valley (p. 761).

Northwest United States and Canada

Prehistoric sites have been found close to sources in the Northwest. Veratic Rockshelter in Idaho (Wright et al 1969) contains obsidian from a source in Yellowstone Park. This may or may not indicate trade was taking place as the distances involved are not great. Sites in the Powder River area of Montana and Wyoming (Frison et al 1968) contain obsidian derived from that area. Sporadic finds of obsidian occur in southern Alberta, Saskatchewan and Manitoba, suggesting some form of interaction since the closest source is in Yellowstone Park.

Interestingly enough, the cultures of the Northwest Coast and Plateau made relatively little use of obsidian although it could be readily obtained close by. They seemed to prefer bone and flint for tools and weapons (Willey 1966).

California and the Southwest

Many of the major archaeological sites in California containing obsidian are located near such sources as Glass Mountain, Clear Lake and Mono Lake. The Borax Lake site (Meighan and Haynes 1970), which is located near Clear Lake, contains an Early Man complex. The Mammoth Junction site (Michels 1969) is close to Mono Lake. Heizer and his associates (1965) have demonstrated that some trade in obsidian was taking place from the Glass Mountain source to areas in the San Francisco Bay and Lower Sacremento Valley region but even so, the distance involved is only about fifty to a hundred miles.

Midwest United States - Hopewell

The source of the obsidian found in the Midwest Hopewell sites has been a topic of interest for a good many years. Some researchers, because of claimed Mesoamerican cultural affinities, have believed in a Mexican or Californian source (Holmes 1910) while others have insisted on the source being in Yellowstone Park. Griffin and his colleagues (1969) at the University of Michigan have positively identified the source of the Hopewell obsidian as Obsidian Cliff and one other source in Yellowstone Park.

The Hopewell followed the Adena people into the southern Ohio region and represent a continuation of the basic pattern of Adena life. The Hopewell culture spread from central and southern Illinois to southern Indiana and Ohio, to Michigan, Wisconsin, Iowa and Missouri. The diffusing elements were primarily associated with burial ritual. They built extensive earthworks in which burials were often placed. These people placed an elaborate store of implements and ornaments, often made of obsidian, with the dead. This is regarded as one of the distinctive features of the Hopewell phase. That obsidian played a substantial role in Hopewell life is made evident by the numerous caches of both worked and unworked obsidian that have been discovered. The Hopewell used high quality flint and obsidian to fashion such artifacts as projectile points, flake knives and finely chipped blades. Obsidian had great ceremonial significance to the Hopewell and they obviously went to great lengths to obtain it.

The Hopewell had a far-flung network of trading relationships. One of the hallmarks of most Hopewell traits is the emphasis on exotic raw materials which were either manufactured into a variety of objects or left deliberately unmodified. One of the most notable features of the decline and disappearance of Hopewell culture was the breakdown of this system of trade in exotic raw materials (Willey 1966: 280).

The exact mechanism of the Hopewell trading network is poorly understood, but both Caldwell (1964) and Struever (1964) postulate that the Hopewell were involved in an "interaction sphere", involving a number of other prehistoric groups. This interaction took the form of riverline communication or intercourse which permitted the geographically separated groups involved in the "sphere" to share an assemblage of imported raw materials and artifact styles. Mainly ideas and unfinished goods moved within this network. Obsidian was obtained in the Yellowstone region and through a sequence of trading relationships, it was spread throughout the Hopewell culture area. It is interesting to note that the use of obsdiian in the Midwest is strictly limited to the Hopewell period (Griffin 1965: 149).

Mesoamerica

Virtually every archaeological site in Mesoamerica has been found to contain obsidian as part of its lithic inventory. As Kidder (1947) states, obsidian has been found in sites from Orosi, Costa Rica in the south, to Guasave, Sinaloa in the north and from the Carribean to the Pacific. The time range for the use of obsidian in Mesoamerica is also quite extensive, from Archaic times (about 3500 B.C.) to the present day.

Most people associate obsidian in Mesoamerica with the long, prismatic blades and polyhedral cores so common throughout Mexico and Guatemala. The tool inventory is actually much broader than this. Both Coe (1964) and MacNeish (1967) describe an inventory of preceramic artifacts dating from Archaic and Preformative times which include: stemmed projectile points, unifacial knives, leaf-shaped knives, ovoid bifacial scrapers, discoidal scrapers, choppers and flake tools. Blade making technology made its first appearance in Middle Formative times, about 2000 B.C.

Later sites rarely contain obsidian artifacts with additional shaping. Most of the artifacts encountered are unaltered blades. The predominance of blades is probably due to the effectiveness of their unaltered, razor-sharp edges (Woodbury 1965). Hence, blades have generally characterized the almost universal Mesoamerican use of obsidian. It was the prismatic blade of obsidian in usage by the Aztecs which so impressed the Spanish Conquistadores.

In the Tehuacan Valley, MacNeish (1967) has traced the development of blade making technology and he has established cultural horizons using blade and core types as markers. He believes further study will establish obsidian blades as horizon markers throughout all of Mesoamerica.

Exquisitely chipped knives are widely distributed in Mesoamerica. Since they are found in ritual deposits and seldom show dulling from use, the belief that they served as knives for human sacrifice is not unreasonable (Op.cit.).

Obsidian used in Mexico and particularly in the Valley of Mexico, was obtained from a number of sources which were relatively close, such as Sierra de la Venta, Sierra de San Andres, Cerro de las Navajas, Pachuca and Otumba. Cerro de las Navajas has been known from Archaic times and was extensively quarried for many hundreds of years. There are extensive obsidian working areas in a number of Mexican sites but the greatest amount of obsidian working debris occurs in Classic and Post Classic sites such as Teotihuacan.

Of great interest is the presence of considerable quantities of obsidian in Classic Maya lowland sites. Flake blades are abundant everywhere. Housemound excavation data indicates that there is no area where flint served alone in the production of cutting tools. In light of the fact that there is not one source of obsidian in the entire lowland Maya area, obsidian seems to have been needed, at the very least, to supplement flint tool complexes and was imported everywhere in quantity (Rathje 1971). Both green and black obsidian was imported into the lowland area; the black variety doubtlessly came from the Guatemalan sources such as Ixtepeque (Kidder 1947). The green obsidian found at Tikal, Copan, Uaxactun, Zacualpa, Piedras Negras and San Jose, to name a few, has been positively identified as originating from the Pachuca source in the Valley of Mexico. Green obsidian is abundant in all the ruins in the northern Yucatan Peninsula so there must have been a heavy trade (Ibid.). Even in the Valley of Mexico, green obsidian was principally used for well-made implements and for the high quality flake-blades; in Guatemala, the material seems to have been restricted entirely to manufacturing such objects, an added indication that it was a highly valued import.

The heavy obsidian trade from the Valley of Mexico to the Maya lowlands has been linked by Spence (1967) to the rapid expansion of the Classic Teotihuacan obsidian industry. He attributes this expansion to an increasing demand by the growing population of the city and the increasing trade demands to the south. Both the Maya and Mexicans had well developed trading systems directly controlled by their bureaucratic state organizations. Although the Maya had ports-of-trade, two cities in the Maya domain may have been controlled from Teotihuacan, namely, Kaminaljuyu and Tikal. These two outposts probably served as distribution centres for goods imported from the Valley of Teotihuacan. Whether obsidian was imported as raw material or as finished goods is not known. The mechanism of the trading network is not fully understood but long distance trade was probably in the hands of specialists known in Aztec times as "pochteca" (Sanders and Price 1968). In this way, obsidian from the Valley of Mexico spread throughout the Maya lowlands. With the collapse of the Classic civilizations in Mexico and Yucatan, this trading network disintegrated, although the Aztecs carried on a certain amount of trade in later times i.e. Cocoa route (Vaillant 1966) .

Obsidian, other than the green variety, was never imported into the Guatemalan highlands in great quantity as there were extensive deposits nearby. Unaltered obsidian flake-blades were the most common stone implements of the Guatemalan highlands (Kidder 1947).

Obsidian was in continuous usage all over Mesoamerica for thousands of years. Through time, the blade making industry became very sophisticated and the demand for this excellent cutting edge caused obsidian to be in demand as an import. Aside from its utilitarian properties, obsidian was also appreciated for its aesthetic qualities. Its color and lustre made it popular for jewellry and decoration, rivalling jade in importance. The obsidian mirrors of the Aztecs were as beautiful as those produced by the Egyptians. But it was the razor-sharp edge which maintained obsidian's popularity. Although the techniques of blade-making have been recorded historically and observed ethnographically, there is considerable interest among prehistorians as to the development of lithic technology in Mesoamerica and indeed, everywhere. In light of the fact that percussion flaking was throughout prehistory the predominant form of stone-working, it is interesting to observe the Mesoamerican phenomenon of blade production by pressure flaking. In the following chapter percussion-flaking and pressure-flaking as they relate to obsidian will be discussed. It is hypothesized that there are techniques of analysis by which artifacts produced by these methods can be differentiated.

CHAPTER IV

OBSIDIAN TECHNOLOGY

There is currently an interest in stone-flaking technology and consequently, in worked obsidian. Because of its glass-like composition, obsidian provides possibilities for the observation of scar phenomena resulting from stone-working activities not usually observable in flint or other materials. This observational clarity is contributing to the development of formal procedures for investigating flaking technology (Anon. 1967).

I. EXPERIMENTAL ARCHAEOLOGY

The interest in technology has become closely associated with what is now called, "experimental archaeology". By careful imitative experiments and observation of the results, archaeologists are attempting to derive direct inferences about prehistoric human activities. The execution of an imitative experiment involves simulating that which is believed to have happened in the past in order to test the reasonableness of that belief (Ascher 1961). The basis of imitative experiments is taken from two general propositions: the first that all cultural behaviour is patterned. This proposition forms the basis for the concept of ethnographic analogy. The other proposition is that, artifacts produced from the same scheme exhibit similarities which permit their division into groups which reflect those schemes. This proposition constitutes an implicit theoretical and methodological base for the execution of imitative experiments (<u>Ibid</u>.).

Ascher (1961) summarizes the process of performing an imitative experiment as follows:

1. converting the limited working hypothesis into a verifiable form by setting up an experiment
2. selecting the experimental materials
3. operating with the objective [raw material] and effective material [tools]
4. observing the results of the experiment
5. interpreting the results of the experiment as an inference.

Thus, as Bonnichsen (1968) neatly puts it, "the emphasis of the experimental approach is to move out of the realm of speculation into the more productive area of testing hypotheses through experimentation".

Practical experimentation has demonstrated that it is possible to produce the same type of artifact by several different technological procedures. The standard course of action for the modern experimenter is to conduct a series of experiments to replicate aboriginal stone tools. After the experimenter has reduced the undesirable elements, such as lack of expertise, he is often able to demonstrate one or more techniques or formulas by which an aboriginal tool type can be replicated (<u>cf</u>. Crabtree). This reconstruction is possible in many cases since the kind of lithic materials chosen by aboriginal peoples has an isotropic or plastic nature (especially obsidian) which records in the material's morphology the kind of force delivered (<u>Ibid</u>.). In essence this means that artifacts of certain materials preserve characteristics of the technology used to produce them. This is particularly true of

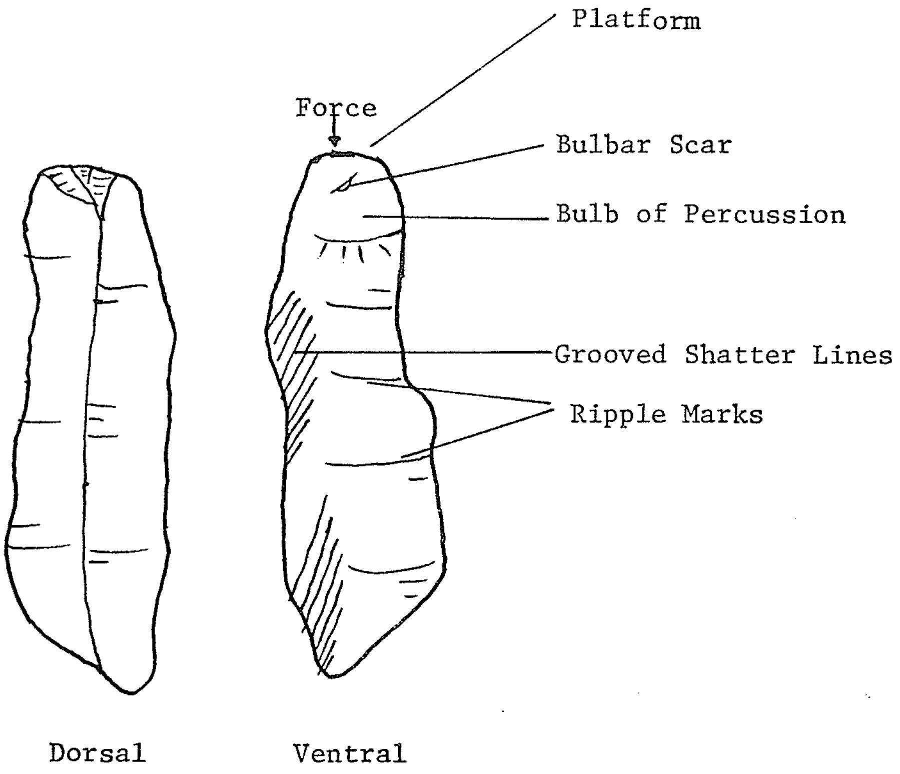


Figure 7. Generalized Flake

obsidian which, because of its unique fracturing properties, preserves a very accurate record of the lithic manufacturing techniques applied to it.

A leader in the research in lithic technology applied to obsidian is Don Crabtree of Idaho State University, who is adept at replicating many types of aboriginal stone tools. Of particular interest to me is his work in replicating Mesoamerican polyhedral cores and prismatic blades of obsidian (1968). He has demonstrated that specific kinds of controlled flaking techniques produce predictable results. Crabtree's experiments have obvious implications for students of Mesoamerican culture but also for those who are interested in the nature of stone fracture. He has demonstrated beyond any reasonable doubt that the impulsive pressure flaking technique is the only method by which the long prismatic blades, so common in Mesoamerica, could have been produced. This provides graphic confirmation of the historical and ethnographic accounts of the production of blades. Research into differential blade morphology has provided MacNeish (1967) with a series of cultural horizon markers in the Tehuacan Valley. This research also lead to the observation that definite changes in stone-working techniques took place in the Valley through time.

II. PERCUSSION VS. PRESSURE - COMPARATIVE LITHIC TECHNOLOGY

As an illustration of the application of imitative experiments and their relevance to lithic analysis, I propose to discuss some research that I conducted at the Laboratory of Anthropology of the University of Manitoba in 1970. This involved the analysis of two groups

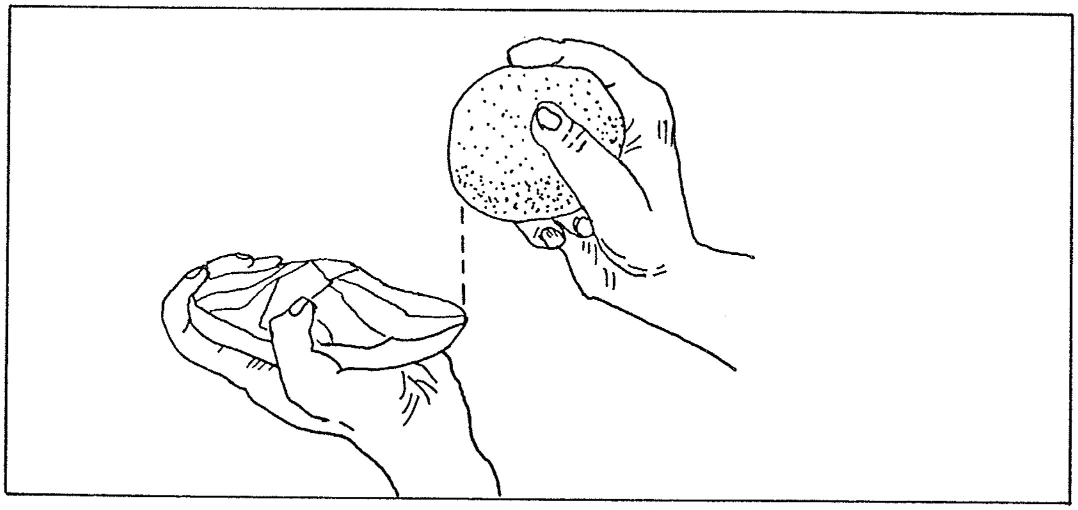


Fig. 8 Direct Percussion - Flaking

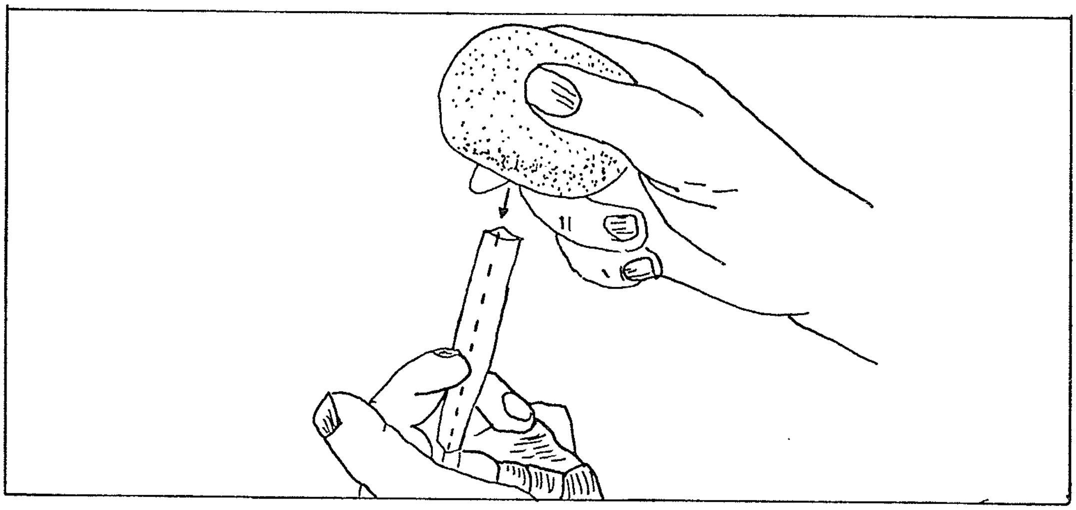


Fig. 9 Indirect Percussion - Flaking

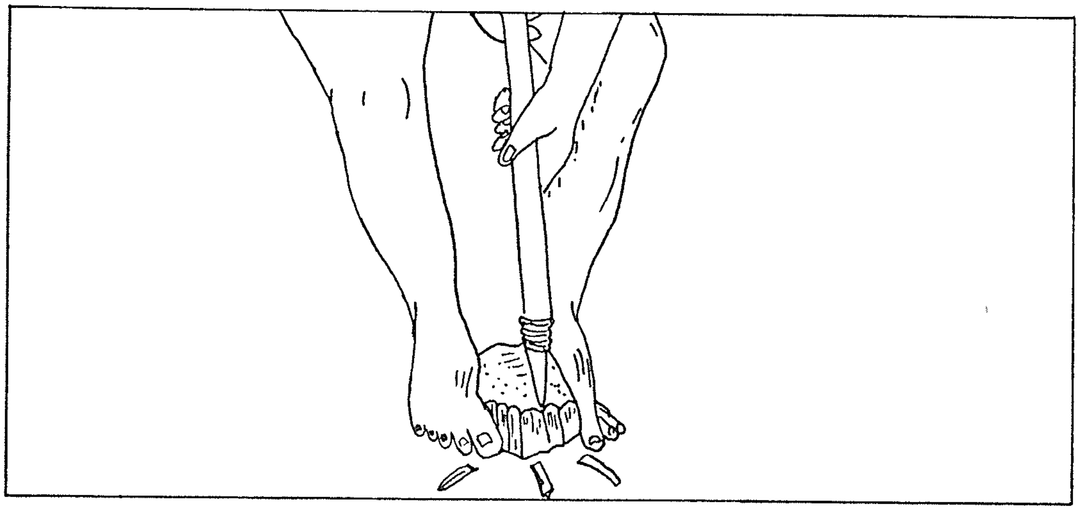


Fig. 10 Impulse Pressure - Flaking

(after Holmes 1919)

of experimentally produced obsidian flakes. Two basic kinds of lithic technology were represented in the samples; percussion flaking (Figs. 8 and 9) and pressure flaking (Fig. 10) divided on the basis of the duration of applied force. The purpose of the analysis was to determine if there were observable attributes which were diagnostic of either technique. In effect, this was an attempt to compare percussion flaking and pressure flaking through analyzing flakes produced by each technique.

The two groups of flakes had been produced by Crabtree from obsidian cores of approximately equal composition. The direct percussion sample included 17 flakes. The pressure sample, 15 flakes (Table II and III). The percussion flakes had been produced by direct hard-hammer percussion with the base of the core supported against a stump; the pressure flakes by applying impulsive pressure with a copper-tipped chest punch (Fig. 10). The core in this case was a machine-sawn rectangular block with surface preparation. These two samples, although small, were expected to reflect any major differences that arose due to the application of the two flaking techniques. Drawings of the flakes are included in Appendix VI.

The flakes were studied under a binocular microscope at from 6-50 power using both polarizing and ordinary light sources. Micronorphological attributes observed were ripple marks, grooved shatter lines and bulbar scars (Mayer-Oakes 1966, Appendix V). These features were the ones which were best suited for analysis because of the ease with which they could be observed and measured. Various

TABLE II

ANALYSIS OF BLADE GROSS MORPHOLOGY

	Length mm.	Width mm.	L/W Ratio	Flake Outline		Platform		Bulf of Force	
				Regular	Irreg.	Large	Small	Pronounced	Weak
1	112	9	11.3:1	X			X		X
2	111	16	6.9:1	X			X		X
3	109	13	8.4:1	X			X		X
4	101	14	7.2:1	X			X		X
5	102	14	7.3:1	X			X		X
6	94	12	7.8:1	X			X		X
7	100	9	11.1:1	X			X		X
8	108	13	8.3:1	X			X		X
9	106	14	7.6:1	X			X		X
10	117	8	14.6:1	X			X		X
11	---	9	----	X			X		X
12	112	10	11.2:1	X			X		X
13	102	11	9.3:1	X			X		X
14	101	12	8.4:1	X			X		X
15	102	13	7.8:1	X			X		X
Average	104.8	11.8	8.9:1						

TABLE III

ANALYSIS OF BLADE-LIKE FLAKE GROSS MORPHOLOGY

	Length mm.	Width mm.	L/W Ratio	Flake Outline		Platform		Bulb of Force	
				Regular	Irreg.	Large	Small	Pronounced	Weak
1	56	20	2.8:1	X		X		-	-
2	41	15	2.7:1		X	X		X	
3	61	25	2.4:1		X	X		X	
4	72	19	3.8:1	X			X	X	
5	67	25	2.7:1	X		X		X	
6	56	17	3.2:1	X			X	X	
7	60	13	4.6:1	X			X		X
8	58	16	3.6:1		X	X		X	
9	57	21	2.7:1		X	X		X	
10	68	24	2.8:1		X	X		X	
11	54	19	2.8:1		X		X		X
12	75	18	4.2:1		X	X		X	
13	73	14	5.2:1	X		X		X	
14	71	19	3.7:1		X		X	X	
15	51	10	5.1:1		X	X		-	-
16	45	9	5.0:1	X		X		X	
17	36	9	4.0:1		X	X			X
Average	57.7	17.2	3.4:1						

measurements and observations were recorded and the resulting data assessed to determine if there were any significant correlations between the observed attributes. The patterns and associations were measured qualitatively, or comparatively, in terms of recurrence and association. The flakes were studied with the aim of discovering patterns of features, recurrence of features and associations of features. The features examined were gross morphology, bulbar scars, ripple marks and grooved shatter lines.

Gross Morphology

During my analysis of the flakes, it became immediately apparent that the two groups could be easily separated on the basis of gross morphology alone (Appendix VI). The pressure-produced blades were long and narrow with an average length-to-width ratio of 8.9 to 1. They were also very regular in form, having parallel edges and smooth, faintly undulating ventral surfaces (Table II). They were also uniformly prismatic in cross-section.

On the other hand, the blade-like flakes produced by percussion were very irregular in size, shape and form. They were much shorter in relation to their widths with an average length-to-width ratio of 3.4 to 1. The edges of the flakes were irregular in outline and the ventral surfaces rough and undulating (Table III).

Although these observations are useful in separating these two groups of unreworked artifacts, they generally prove useless in analyzing flakes whose original form has been altered by accidental breakage or deliberate retouching. Consequently, other attributes which remain

TABLE IV

ANALYSIS OF BLADE MICROMORPHOLOGY

	Ripple Marks				Bulbar Scar		Grooved Shatter Lines		
	Frequency		Amplitude						
	High	Low	High	Low	Present	Absent	∠//short	∠//long	Fan-shaped
1		X		X		X	X	X	X
2		X		X		X		X	
3		X		X		X	X		X
4		X		X		X	X		X
5		X		X		X	X		
6		X		X		X		X	
7		X		X		X	X		
8		X		X		X	X		
9		X		X		X		X	
10		X		X		X	X		
11		X		X		X	X		
12		X		X		X	X		
13		X		X		X		X	X
14		X		X		X	X		
15		X		X		X		X	

TABLE V

ANALYSIS OF BLADE-LIKE FLAKE MICROMORPHOLOGY

	Ripple Marks				Bulbar Scar		Grooved Shatter Lines		
	Frequency		Amplitude						Fan-Shaped
	High	Low	High	Low	Present	Absent	∠ //short	∠ //long	
1		X		X		X			X
2	X		X			X			X
3	X		X		X				X
4	X		X		X			X	X
5	X			X	X				X
6	X		X			X			X
7	X			X	X			X	
8	X		X			X			X
9	X		X		X				X
10	X		X		X				X
11	X		X		X			X	
12		X		X	X				X
13	X			X	X				X
14	X		X		X			X	
15	X		X			X			X
16	X		X			X	X		X
17	X		X		X			X	

after alteration must be used to study reworked flakes. The key attributes for the analysis of reworked flakes are those which are not likely to be altered by retouch. They are likely to be intrinsic to the very nature of the raw material involved. Obsidian exhibits some unique and persistent properties under various fracture-producing conditions. As was mentioned above, these properties manifest themselves in an indelible record on the artifact. Some of the more general observations concerning the record preserved in obsidian artifacts noted by Morgan (1967) and Crabtree (1968) previously include the following: artifacts produced by direct percussion had large platforms, pronounced bulbs of force, platforms often crushed by impact, numerous strong undulations on the inner facet and an irregular flake outline. Artifacts produced by pressure flaking had smaller platforms, less pronounced bulbs of force, platform preparation, regular blade outline and weak undulations on the inner facet (Appendix VI). Of these observations, those regarding general shape and form were considered useless in the analysis of reworked flakes. Of the remaining general observations, the undulations or ripple marks on the inner facet are the only ones useful in the analysis of reworked artifacts as those dealing with platforms and bulbs were eliminated because they were often altered during rework.

As the number and intensity of ripple marks was best observed with the aid of a microscope, they were included with the other micromorphological attribute systems, bulbar scars and grooved shatter lines. These three attributes were deemed the most useful in the analysis of reworked obsidian artifacts (Tables IV and V).

Bulbar Scars

Although bulbar scars are usually readily apparent with the naked eye, they are sometimes only a millimeter in width and must be examined with a microscope to determine if they are indeed bulbar scars. As they are quite complex, often having their own internal arrangement of ripple marks and shatter lines, they are regarded as a system (Mayer-Oakes 1966). No attempt was made to assess the cause of the great variation in size, shape and internal complexity of bulbar scars as this seemed directly related to the physics of force application. The factor of greatest relevance concerning bulbar scars and their relationship with flaking techniques turned out to be simply presence or absence. Bulbar scars appear only on flakes produced by percussion flaking (Semenov 1964, Morgan 1967, Crabtree 1968 and Mayer-Oakes n.d.). I found that none of the pressure-produced blades in my sample possessed a feature which could be classified as a true bulbar scar, although only about 64% of the percussion-produced flakes had bulbar scars. The other 36% had no bulbar scars, often due to platform collapse or hinge fractures. On this basis, it would seem that the presence of a bulbar scar probably indicates initial production by percussion flaking.

Ripple Marks

These undulations on the inner facets of flakes can be related to the type of force applied. They vary greatly in frequency and intensity. I found this variation to be a manifestation of the intensity and duration of the force applied (Appendix V). The more rapid and intense the application of force, the more rapid the elastic oscillation of the obsidian and the more frequent and intense the "wave" frequency. Observing the two samples verified this. The ripple marks on flakes produced by percussion are pronounced and frequent, whereas those on blades produced by pressure flaking are weakly developed and are virtually immeasurable.

I found it more profitable to express the intensity and number of ripples in qualitative terms rather than in absolute measurements as, especially in the case of ripple amplitude, they were very difficult to measure. Thus, the relative number and intensity of ripples in the two samples was determined (Tables IV and V). Some individual flakes exhibit considerable variation over their ventral surfaces but in general, flakes with faintly undulating ventral surfaces (weak and infrequent ripples) were produced by pressure flaking and those with intense and frequent ripple marks are the products of percussion flaking. In cases of incomplete or altered artifacts, the part of the flake which remains may not be representative of the entire flake.

Grooved Shatter Lines

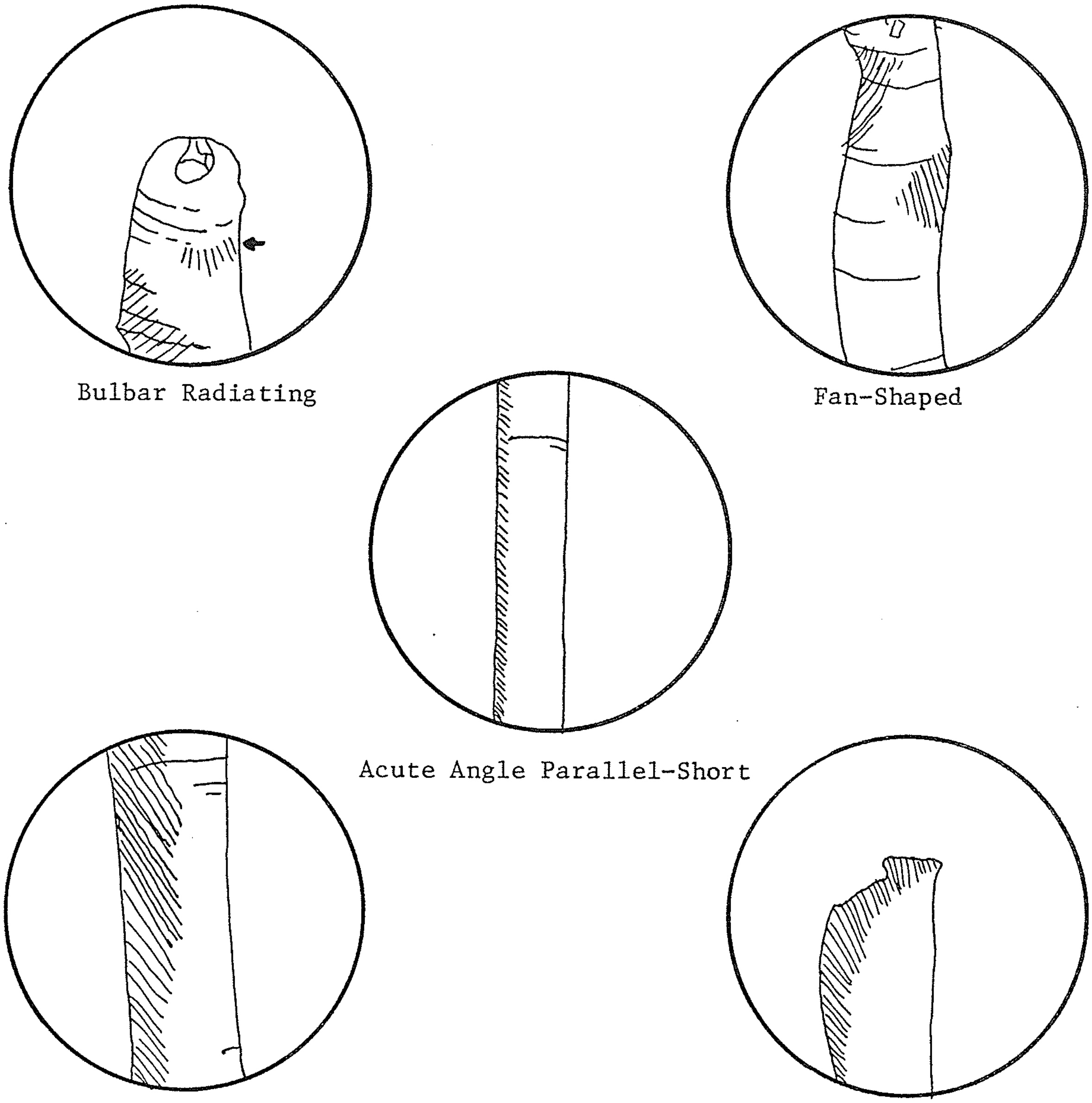
Grooved shatter lines (Fig.7) are felt to be the most profitable area for intensive research of lithic technology (Crabtree 1968, Bonnichsen 1968, Mayer-Oakes n.d.). The fact that they demonstrate a great deal of patterned variation makes them amenable to comparative studies. For example, Crabtree (1968) feels that when the phenomenan of these fissures is studied and understood, it will provide a means of determining the difference between percussion and pressure flaking. A good deal of the difficulty in studying GSLs stems from the fact that little is understood about the processes which create them. The first attempt to explain them was by McCurdy (1900) who stated that GSLs represent multitudinous planes of fracture parallel to one another, penetrating, on the one hand, the core and, on the other, the flake, probably at right angles to their common surface of fracture. This is an accurate description but it falls short of explaining their formation. Unfortunately, little research has been carried out which attempts to explain the formation of GSLs.

There were certain patterned regularities among grooved shatter lines. Although they may not be directly related to the type of force applied, they do have definite relationships with other features and attribute systems for which a mode of production has been determined. Mayer-Oakes (n.d.) discusses two types of patterning: the overall patterning of groups of lines, and the variations of individual lines in plain view.

In most cases, the variation in individual grooved shatter lines was directly related to the overall GSL pattern (Fig.11). A specific type of GSL was often associated with a specific GSL overall pattern. Therefore, I felt justified in concentrating my research efforts on overall GSL patterning which was much simpler to evaluate. The individual GSL patterns may be a good method of determining technology but this will require further research.

In general, I found that there is a relationship between flake outline and the GSL pattern but this relationship is by no means universal as individual flakes often possessed more than one type of

Figure 11 . Grooved Shatterline Pattern Variants



Bulbar Radiating

Fan-Shaped

Acute Angle Parallel-Short

Acute Angle Parallel-Long

Distal-Radiating

overall pattern. The significant GSL patterns observed in the two samples were: bulbar radiating, fan-shaped, acute angled parallel-short, acute angled parallel-long and distal radiating (Fig. 11).

The bulbar radiating GSL pattern is found on or just below the bulb of force. These GSLs are generally short and radiate from the point of force application. They are infrequent in both samples, and thus their presence could not be used to discriminate the flaking types.

Fan-shaped GSL patterns tend to be directly related to edge irregularity (curvature) and strong surface undulations (ripples). Inner facet undulations in the form of strong ripple marks and edge irregularity are common features of the blade-like flakes. Unfortunately, this pattern was not a universal feature of percussion-produced flakes (only about seventy-six per cent had fan-shaped GSLs). At the same time, about twenty-seven per cent of the pressure-produced blades also possessed fan-shaped GSLs (Table IV). The most positive statement that one can make concerning the appearance of this type of GSL is that there is a good chance that the flake was originally irregular in shape and/or strongly rippled. In other words, the fan-shaped GSL pattern is a poor indicator of the percussion flaking technique.

The two types of acute angled GSL patterns were also found on both types of flakes in direct association with edge and surface regularity. Most were associated with long, parallel edges. The shorter variation of this pattern, extending less than ¼ of the way across the flake, is almost exclusively limited to the very regular but thick blades (more than 3 to 4 mm. in thickness) with high edge angles. The long variation, extending more than ¼ of the way across the flake, is found on blades which are regular in shape but thin (less than 3 to 4 mm) with low edge angles. On blades, the GSLs are evenly spaced and all tend to be of approximately the same length, usually persisting most of the length of one edge. However, on blade-like flakes, the pattern rarely persists for any distance and is often irregular in length and intermittent in occurence. This pattern does not appear with any kind of regularity, even on blades, being absent on some and present on others. The fact that GSLs sometimes appear only on one edge of blades may be an operator induced variant or a function of blade thickness. When they do appear, they are always on the edge with the lowest edge angle. The relationship of this pattern to edge and surface regularity seems to be direct, ie. it is found only with straight edges and relatively smooth ventral surfaces. Thus, an obsidian artifact that has been altered so that the original edge and ventral surface are no longer discernible, which possesses an irregular GSL pattern, it is safe to assume that the edge and/or the ventral surface was irregular. Further statements about technology need to be supported.

Distal radiating GSLs were rarely encountered and they were found to be present in both samples, associated with a thin, jagged distal area. Their low frequency and presence in both samples negates their usefulness in technological reconstruction.

Conclusions

I have outlined the following features as being the most valuable in assessing obsidian lithic technology:

1. gross morphology

2. bulbar scars
3. ripple marks
4. grooved shatter lines

To test this hypothesis, I examined the significance of these features correlated with each other and the technology represented. The correlations were tested by using Chi-square in the form of a 2 X 2 contingency table. Yates correction factor was not applied because two separate populations of flakes are represented. The Chi-square formula is:

$$\boxed{X^2 = \sum \frac{(O - E)^2}{E}}$$

Where O = observed frequency

E = expected frequency

The contingency table is set up as follows:

	X	Y	Totals
Group 1	a	c	e
Group 2	b	d	f
Totals	g	h	k

The Chi-square calculation applied to the contingency table is:

$$X^2 = \frac{(bc - ad)^2 K}{efgh}$$

The four correlations examined were:

1. bulbar scars with percussion produced blade-like flakes (BLFs)
2. large and frequent ripple marks with irregularly shaped flakes
3. acute angled GSL pattern with long, straight edges
4. fan-shaped GSL pattern with edge curvature and strong ventral undulation ie. percussion-produced BLFs.

The calculations were as follows:

1.

	Bulbar Scar	No bulbar scar	Total
Blades	0	15	15
BLFs	11	6	17
Total	11	21	32

$$X^2 = \frac{(11.15 - 0.6)^2 .32}{15.17.11.21}$$

$$= \frac{871200}{58905}$$

$$= 14.8$$

Checking this value for X^2 at one degree of freedom on a table of Chi-square, it was found that the value obtained was significant at greater than the .001 level. This indicates that the correlation hypothesized is highly significant, ie. that presence of a bulbar scar indicates the flake was produced by percussion.

2.

	Regular Flakes	Irregular Flakes	Totals
Large, frequent ripples	0	11	11
Low, infrequent ripples	17	0	17
Totals	17	11	28

$$X^2 = \frac{(11.17)^2\ 28}{11.17.17.11}$$

$$= \frac{979132}{34969}$$

$$= 28$$

This X^2 value was also significant at greater than the .001 level. This indicates that the correlation of large, frequent ripples with irregular flakes and low, infrequent ripples with regular flakes is highly significant. As all of the irregular flakes were produced by percussion and most of the regular flakes by pressure, the ripple marks are a good indicator of technology.

3.

	Long, straight edges	Not long, straight edges	Total
Acute angle GSL pattern	15	6	21
Other GSL pattern	4	13	17
Total	19	19	38

$$X^2 = \frac{(4.6 - 15.13)^2\ 38}{21.17.19.19}$$

$$= \frac{1111158}{128877}$$

$$= 8.6$$

This X^2 value is significant at the .01 level. This indicates that there is a significant correlation between long, straight edges on a flake and the acute angled GSL pattern. Thus, this pattern is a fairly strong indicator of pressure flaking.

4.

	Blades	BLFs	Total
Fan-shaped GSL pattern	4	13	17
Other GSL pattern	14	6	20
Total	18	19	37

$$X^2 = \frac{(14.13 - 6.4)^2\ 37}{17.20.18.19}$$

$$= \frac{923668}{116280}$$

$$= 7.9$$

The X^2 value is significant at the .01 level. There is a significant correlation between the fan-shaped GSL pattern and blade-like flakes (BLFs).

Therefore, in the sample of experimentally produced flakes that I examined, the presence of certain features proved to be high level indicators of the technology employed in flake manufacture. While it would be unwise to extrapolate these results to the analysis of lithic artifacts, especially to non-obsidian artifacts without a great deal more research, this superficial study does point out the direction that research can take.

Speth (1972) makes the point that further research into the technological aspects of flake production should lead to a significant reduction in the total number of attributes needed to quantify technological variability, and to the replacement of dozens of arbitrarily chosen and redundant measurements presently in vogue with a considerably smaller number of attributes carefully selected on the basis of sound theoretical principles.

CHAPTER V

SUMMARY AND CONCLUSIONS

Obsidian is probably the most versatile material available to the archaeologist because it can be used for dating, tracing material sources and for detailed technological analysis. Artifacts can be dated using the obsidian hydration dating technique so that site and regional chronologies can be determined. The hydration technique is accurate, inexpensive and easy to perform. There are still some questions to be answered about the determination of hydration rates particularily from reconstructed paleoclimatological evidence. Another problem being studied deals with the factors which influence rates such as chemical composition. These problems are being intensively investigated and it is hoped they will be surmounted in the near future. Once this task is achieved the technique will be established as one of the most important absolute dating tools available to the archaeologist.

Analysis of the trace elements in obsidian using neutron activation or spectroscopic techniques provides a means whereby obsidian artifacts can be linked to their ultimate sources. In this way the sources of the midwestern Hopewell obsidian were traced back to Yellowstone Park and the green obsidian of the Maya lowlands to Pachuca in Mexico. Prehistoric trading patterns can be traced and inferences about the nature of cultural interaction can be achieved. The ongoing program of obsidian analysis is providing data about all the obsidian sources discovered to date, from Guatemala to Alaska. Once all the sources are characterized any obsidian artifact will be traceable to its natural source.

Obsidian, of all the lithic materials available to prehistoric man, preserves the best record of the type of technology used to work it. By observing the patterns and associations of certain morphological features such as bulbar scars, ripple marks and grooved shatter lines, it is possible to infer the type of flaking technique, either percussion or pressure, used. Using experimental techniques to replicate obsidian artifacts and observing the record of fractures, inferences about the nature of prehistoric stone-working techniques can be made. Further progress in this area will be dependent upon research into the physical aspects of obsidian fracture, specifically the processes which create such features as grooved shatter lines and bulbar scars. Once this research has been accomplished it will be possible to directly infer the type of technology used to create artifacts of obsidian and perhaps other isotropic materials such as flint and chalcedony.

The study of obsidian is recent and is consequently only in a developmental stage but the promise of a number of versatile research tools is encouraging archaeologists to continue improving their research. In a profession where versatility is paramount, a material as valuable as obsidian should soon become indespensable.

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APPENDIXES

APPENDIX I

HYDRATION LABORATORY EQUIPMENT AND MATERIALS

"Item: Polarizing Microscope (Vickers)

Specifications: interchangeable inclined monocular tube which is unobstructed for at least 3.6 inches down from the top; circular centering and revolving object stage 120 mm. in diameter; regulating 6 volt transformer; achromatic dry objectives - 3.5, 25, 45x; achromatic oil immersion objective - 90 - 100x; quartz wedge 1. - lv. order.

Function: To permit clear observation of the hydration rim.

Item: Fillar Screw Micrometer Eyepiece

Specifications: magnification of 10-12.5x.

Function: device by which accurate measurements of the width of hydration rims are obtained.

Item: The Cooke AEI Image Splitting Eyepiece

Specifications: magnification of 10x.

Function: device by which accurate measurements of the width of hydration rims are obtained.

Item: Stage Micrometer 1/100 mm

Specifications: none.

Function: to permit individual analysts to control for instrumental and individual error during the measuring process.

Item: Craftsman Dial Test Indicator No. 4076

Specifications: none.

Function: device by which quick, accurate measurements of the thickness of the specimen thin-section during grinding are obtained.

Item: Hot Plate

Specifications: the surface area should not be less than 114 square inches. Heat must be distributed over the entire surface and thermostatically controlled; a heating capability of up to 60 degrees centigrade is required.

Function: to permit proper mounting of thin-section onto micro-slide and, subsequently, to permit proper cover glass mounting.

Item: Horizontal Lapidary Machine

Specifications: a smooth, hard-steel lap 6 - 10 inches in diameter, capable of revolving at a speed of approximately 200 RPM.

Function: device by which preliminary grinding of thin-section is quickly accomplished.

Item: Water-Cooled "Cut-Off" Saw

Specifications: a very stable, precision-tooled machine which produces very little lateral vibration in the revolving saw blade, powered by an electric ½ H.P. motor with 1725 RPM which produces a 3000 RPM cutting speed.

Function: to permit satisfactory removal of the thin-section from the artifact specimen.

Item: <u>Continuous Rim Diamond Abrasive Blade</u>

Specifications: 4 inches in diameter; 0.015 inches thick; centre hole - 5/8 inches in diameter.

Function: To cut the wedge from the obsidian artifact.

Michels specifies a number of other items, but these need only brief mention here. He recommends: three pieces of glass for grinding and cooling platforms; a gem carbide scriber for marking micro-slides and metal tweezers for handling the wedges.

Item: <u>Expendable Supplies</u>

Micro-slides (size 25 x 45 x 1.16 - 1.27 mm.)
Micro-slide boxes (for slides of above specifications)
Micro-slide cover glasses (size: 22 x 22 mm. square)
Bars of Lakeside No. 70 cement
Canada Balsam - Neutral filtered
Abrasive Grit size 400*
American Optical 303-½ Corundum Powder
Single-edged Heavy Duty "Razor" Blades

APPENDIX II

PREPARATION AND MOUNTING OF THIN-SECTIONS

As each wedge or thin-section is to be mounted on a slide, the specimen number should be inscribed on each slide.

The speciments can now be taken to the saw and cut. A place on the edge of the specimen "where there is clear evidence of cultural flaking or grinding" (Michels 1965: 224) should be selected for the cut. Specimens showing original cortex, patination or weathering should be ignored.

Two parallel cuts at right angles to the edge of the artifact about 1 mm. apart and about 1 cm. in depth, are made. Care should be taken not to chip the edges of the wedge. The wedge is snapped out of the specimen using the edge pressure of a thin blade or scalpel.

One side of the wedge must be ground flat and smooth. The wedge is ground on the revolving lap for about 30 seconds using the tip of the index finger to support it. The wheel is moistened with a slurry made of fine abrasive, grit size 400. The wedge is now finish-ground on a glass plate covered with a 303-½ corundum powder slurry. The wedge is lightly ground again using the index finger. About 50 cycles on the plate is sufficient. The ground side must be pencil marked for identification and the wedge rinsed.

Next, the micro-slide is placed on the hot top which is maintained at about 52 degrees centigrade. A drop of Lakeside No. 70 cement is placed in the centre of the slide and this melts in about one minute.

The bubbles dissipate in three to four minutes. The wedge is then picked up with the tweezers and placed, ground side down, in the centre of the pool of cement. The slide is immediately removed and placed on a cool piece of glass. Pressure is applied to the wedge for approximately 30 seconds to ensure a good bond. The slide is then left to sit for eight to 12 hours before the other side is ground.

The second side is ground down to a thickness of approximately 2.5/1000 of an inch. The slide is placed, wedge side down, on the slurry covered (grit size 400) lap wheel for about two minutes or until a thickness of about 5/1000 of an inch is reached. The thickness should be constantly checked with the Dial Test Indicator.

When a thickness of 5/1000 of an inch has been achieved, the slide is rinsed and transferred to a glass plate covered with a slurry of 303-½ corundum powder. Using a figure-eight motion, the slide is ground down to the desired thickness of 2.5-3.0/1000 of an inch. The thickness must be checked constantly.

Following grinding on the glass plate, the slide is rinsed and allowed to dry. The slide is then placed (wedge side up) on the hot top and a drop of Canada Balsam is placed on the thin-section. The air bubbles are allowed to dissipate and a cover glass is placed on top. The cover glass is lightly tapped to remove air bubbles. The slide is then put aside to cool. It is now ready for measurement.

APPENDIX III

DETERMINATION OF CALIBRATION FACTOR

"The first step in the procedure to determine one's calibration factor is to choose the ocular and objective to be calibrated. Place the stage micrometer (1/100 mm.) in the microscope, oriented so that the stage micrometer graduations are parallel with the sweep hair of the eye-piece. Pick any stage micrometer graduation in the centre of the field and align the sweep hair in the exact centre of this stage micrometer graduation. Observe the reading on the rotating drum of the eye-piece.

Next, track the sweep hair across to the centre of the next graduation (to the right) and observe the second reading on the rotating drum of the eye-piece. Subtract the first from the second reading, record and repeat the above operations three or four times. Take the average of the total differences (operations).

Each minor division on the stage micrometer equals 10 microns (1 mm. equals 1000 microns, and the stage micrometer is graduated in 1/100 mm.). The eye-piece drum is graduated in 100 units. The relation between these units and micron-units is a function of the magnification being used. It is the technician's calibration factor which relates these two. The calibration factor is the micron value per drum unit (μ/u).

If the technician's average of stage micrometer measurements is less than one complete drum rotation, he should divide his measurement value into 10. For example, if the average measurement value is 8.0 u, then divide this into 10 µ which yields 1.23 µ/u. If the technician's average of stage micrometer measurements is more than one complete drum rotation, perform the same operation. If the average measurement value is 10.0 u, then divide this again into 10 µ, which yields .92 µ/u. In either case, the result is the technician's calibration factor."

APPENDIX IV

OBSIDIAN HYDRATION MICROSCOPE PROCEDURE

"The slide (thin-section) is inserted under a moderately high power objective (ca. x45) and brought into focus.

The slide is slowly moved toward the centre of the stage until an edge of the thin-section is observed. This edge may or may not be one which contains a visible layer of hydration.

Assuming that the first edge encountered shows a measurable hydration rim, the edge is searched carefully by moving the slide so that the thin-section edge remains near the centre of the optical field. The direction (up or down) to be followed along the edge is immaterial.

Choice of a position (location) for measurement is "partially randon"; i.e., the first portion of hydrated edge encountered which seems suitable to the analyst in terms of illumination and clarity for precise measurement is chosen. Thus, the analyst selects from numerous alternatives within any optical field, the "best" location for measurement... Certain other fine points determine the choice of one possible location over another: e.g., presence of jagged, irregular, or fuzzy edge-interface lines, or lines which appear acutely non-parallel.

After a position is chosen, an estimate of rim thickness is made by inspection (or by comparison with the etched graduations on the micrometer eye-piece). If, for example, the hydration is something less than 2 microns, an oil immersion (x 100) will be substituted for the dry objective. Should the hydration be greater than about 20 microns, the analyst may revert to a x25 objective, which permits finer resolution of the lines to be measured.

The analyst now (superimposes) the sweep hairline (controlled by the rotating knob of the micrometer eye-piece) upon the outer edge of hydration. If the hydrated portion has been properly focused, this portion will also constitute the top of the edge of the thin-section. The edge itself should appear as a dark line of a thickness varying not more than the width of the hairline itself. It should not be confused with the Becke line (which appears prominently in some specimens but which reflects the base, not the top of the edge). After recording the setting on the eye-piece knob, the knob is turned so that the hairline is tracked across the band of hydration, coming to rest directly on the interface line.

Should this boundary separating hydrated and non-hydrated portions be especially thick or blurred, special care is taken to set the hairline in the exact centre of the interface. This reading is then recorded above the first figures, and the difference found.....a duplicate measurement at this same location is made, and the average of the two is determined. Normally, the repeatability (i.e., the ability of a skilled analyst to reproduce his reading) is one or two tenths of a micron...infrequently, a reading "blunder" may occur in taking the duplicate measurement, such that the analyst will fail to duplicate himself within three or four tenths of a micron. In this event, he will take a third reading at the same location. All such readings are averaged, unless one happens to fall glaringly outside the range of its members, whereupon it is discarded.

The analyst recommences his search along the edge of the thin-section for a second, and following this, a third "partially" random location for measurement. Subsequent measurements should always, if hydration is adequate, be taken well outside the visual field of the earlier measurements. Ideally, the locations should be a good sampling of the entire perimeter of the thin-section, although this may not always be feasible.

Once the analyst has taken four measurements, an average value is calculated by dividing the sum of all measurements by four. The resulting value is then multiplied by the analyst's calibration factor to produce the "corrected" micron-value of the hydration rim.

Assuming that no hydration is found at the first edge, the analyst will search along the edge until a hydrated edge is located. Almost invariably, hydration will be found on one of the two to several edges of the thin-section. Should none be found, the thin-section will be discarded and another thin-section be cut from the artifact. Should no hydration be found on the second specimen, it may be a reasonable thought that the obsidian artifact is of modern manufacture.

Petrographic features which may make the hydration obscure, include the presence of abundant crystallites, microlites, magnetite grains, or inclusions. Compounds such as iron oxides, which color the section, also may affect the quality of the measurement. Some edges are destroyed or distorted by appreciable crystallization (devitrification) or presence of such structures as collapsed vesicles. Other processes, such as burning or abrasion of the artifact specimen, may also destroy part or all of the hydrated edge. Finally, jagged edges may be caused by spalling (on extremely ancient specimens) or by faulty preparation, especially when the edges are overground.

The analyst should search the entire section before concluding his measurement. This will ensure whether alternate hydration, i.e., a discretely different magnitude of hydration, might be present. An examination of all parts of the section will permit the analyst to judge whether the encircling rim of hydration is uniform. Observation thus far suggests that variability is caused either by wear or a slight abrasion of the artifact surfaces after interment, or by minute chipping of the edge during the sectioning operation...."

The same procedure applies to the image splitting eye-piece, except that an "edge-to-edge" reading is taken. To measure the width of the hydration rim, establish an edge-to-edge setting (images of hydration rim just touching), then track across until the reverse of the original edge-to-edge setting is achieved. The total amount of micrometer run read-off constitutes the "raw" width value. This value is divided by two, since two hydration rim widths have been transversed, and then multiplied by the calibration factor to obtain a "corrected" hydration rim width measurement. (*Ibid.*: 237)

APPENDIX V

STONE FLAKING - BASIC CONCEPTS

Attribute

"An attribute is any logically irreducible character or property of artifacts having two or more states (present/absent), acting as an independent variable and assumed by the observer to be of significance with reference to the frame of his study." (Clarke 1968: 42)

Blade

A blade is a specific type of flake generally described as being long and thin with parallel edges. Blade removal requires a specific type of core preparation and a high degree of technological refinement. Due to their thinness, low edge angle and long edge, blades make very efficient cutting tools with no modification. (Semenov 1957)

Blade-Like Flake

These are flakes which are roughly blade-like in form but which lack the length and uniformity of true blades. They are generally shorter and broader and rarely possess parallel edges.

Bulb of Force

This curved bulge below the platform on flakes is the direct result of the propogation of wave and fracture mechanics in isotropic materials. It is larger and much more pronounced on percussion-produced flakes.

Bulbar Scar

D-shaped flake scars which originate from grooved shatter lines, perhaps where these lines have encountered internal flaws in the course of their development (Morgan 1967: 46). Morgan indicates that the kinds of stresses which produce bulbar scars can only be created by the percussion technique. Bulbar scars are infrequently found on other areas of flakes but most often on the bulb.

Fracture

Fracture is a phenomenan wherein molecular cohesion is lost and the body collapses under stress (Morgan 1967). Fracture occurs when the material is sufficiently stressed. Fracture is influenced by such variables as: direction, intensity and duration of force and the nature of the material. Conchoidal fracture is characteristic of obsidian. This is the tendency for the line of cleavage to curve producing a shell-like fracture.

Grooved Shatter Lines

These lines (grooves) appear in radiating patterns on the bulbs and inner facets of flakes. Grooved shatter lines also point to the direction of force application (Crabtree 1968: 468). They take several types of form, seemingly dependent on the general shape of the flake and/or the type of force. They may represent escarpments between different planes of the same fracture moving in one direction (Stanworth 1950: 73). In any case, several authors feel that they may be the key to understanding fracture mechanics as they apply to lithic manufacturing techniques.

Platform

The platform is the area adhering to the flake where force was applied to the core to remove it. Platform preparation prior to force application increases the worker's control over the fracture.

Percussion Flaking

This is probably the oldest technique of working stone. This technique involves the removal of flakes by a sharp blow with a hammer of stone, wood or bone. The load (force) is applied by impact (duration of loading lasting only microseconds) (Speth 1972: 37).

Pressure Flaking

This is a more sophisticated method employed in doing fine retouch or for removing long, thin blades from cores. Rather than a sharp blow, force is applied slowly (duration of loading up to a second or more) (*Ibid*.).

Ripple Marks

These undulations on the inner surface of flakes are the result of wave propogation and plastic flow (Morgan 1967). Their creation and form is analogous to waves in water. Ripple marks are more numerous and closely spaced when the force has been applied rapidly (Stanworth 1950: 72). Ripple marks indicate the direction of force application. They curve concavely in relation to the proximal end of the flake.

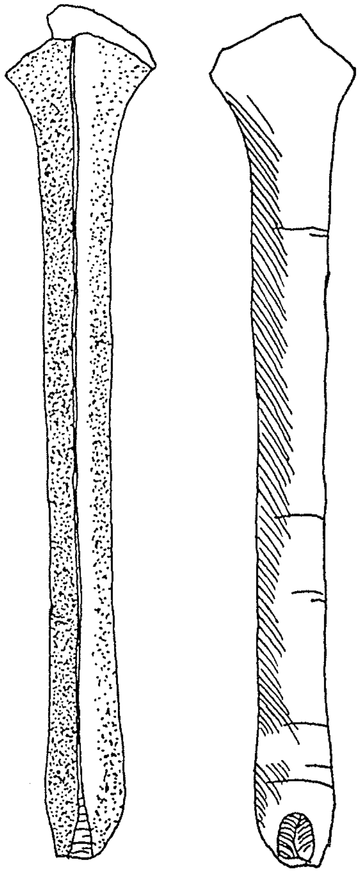
APPENDIX VI

BLADES AND BLADE-LIKE FLAKES

In each of the following drawings, the figure on the left represents the dorsal view and the one on the right, the ventral view or inner facet.

My thanks to Dr. Mayer-Oakes for providing copies of the drawings originally made of the flakes by Virginia Gerulis.

BLADES



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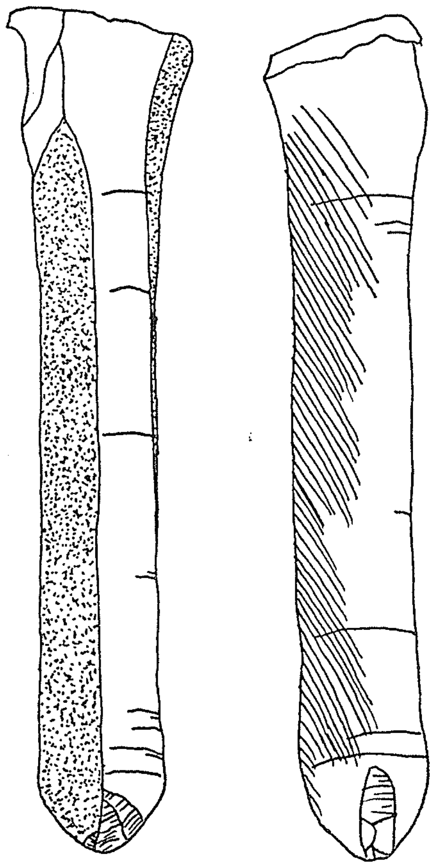

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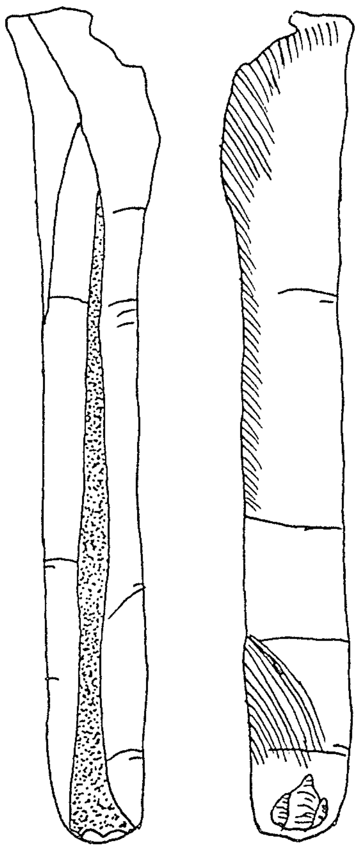

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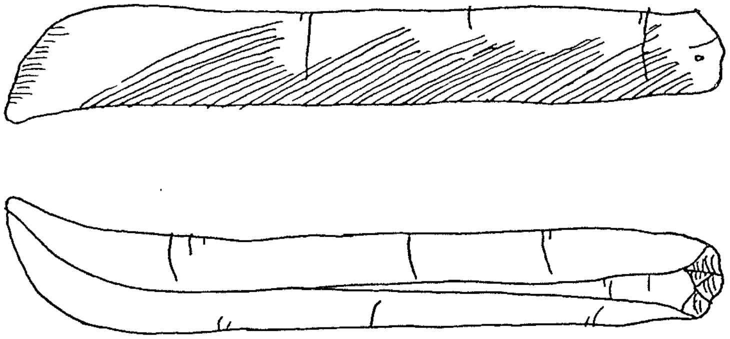

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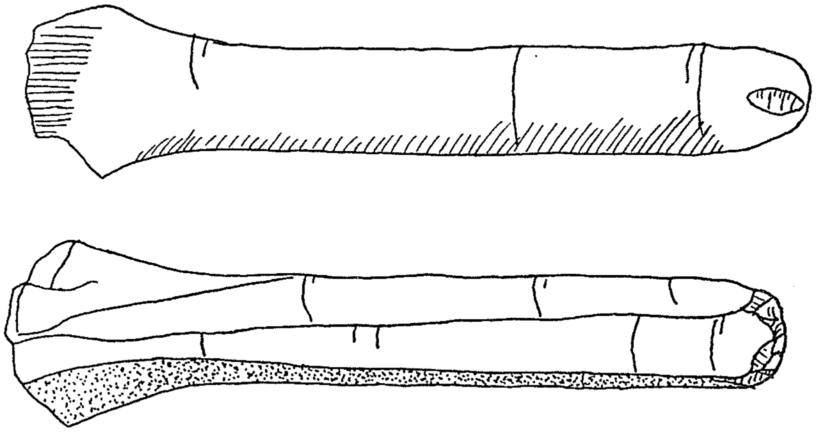

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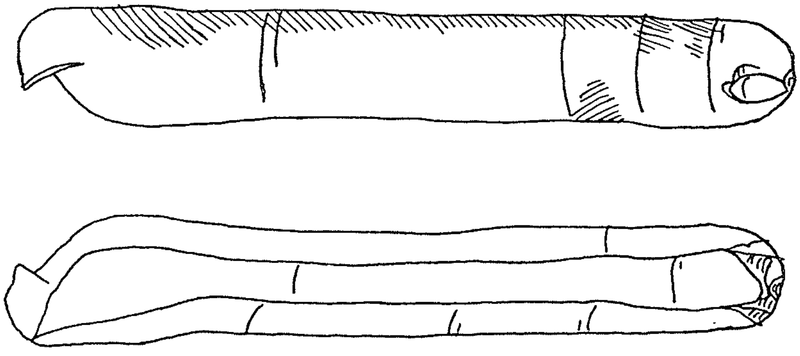

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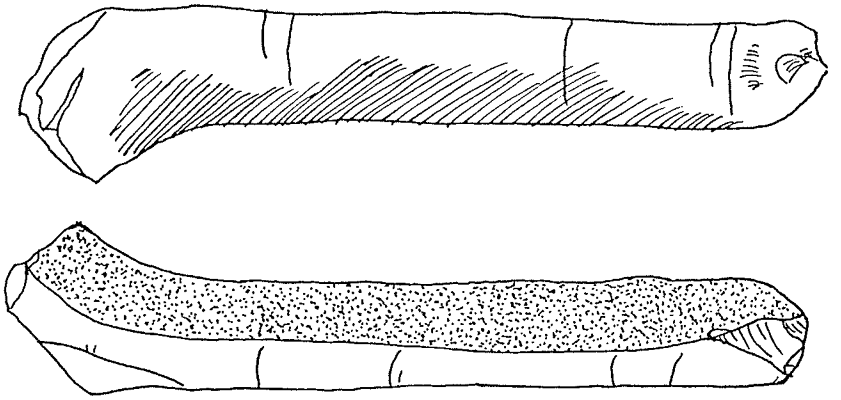

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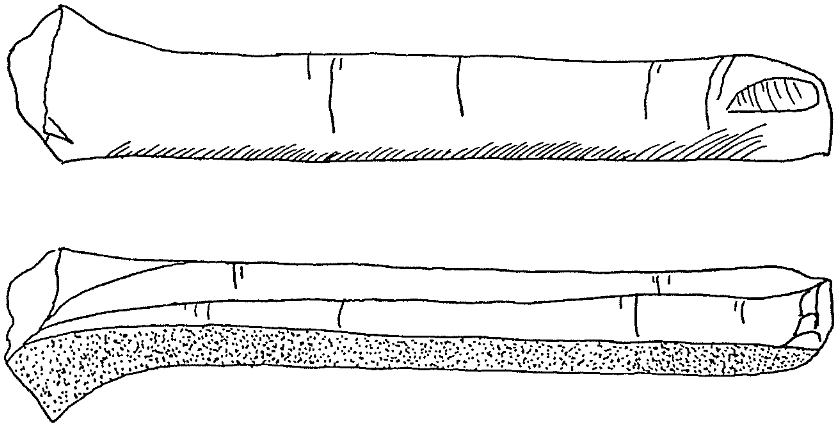

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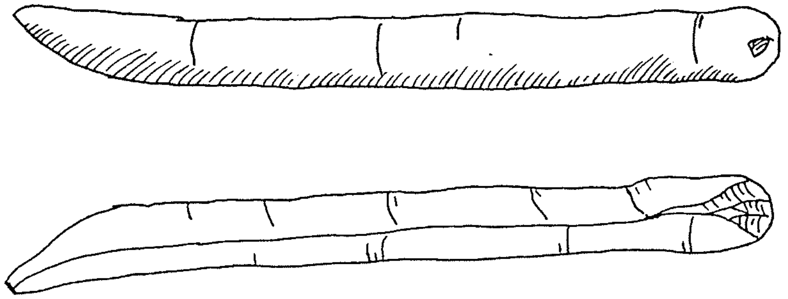

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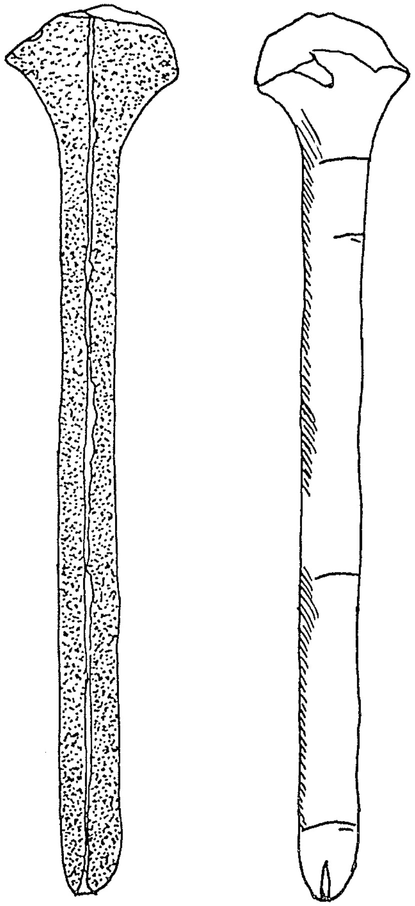

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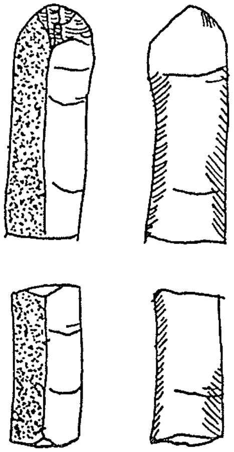

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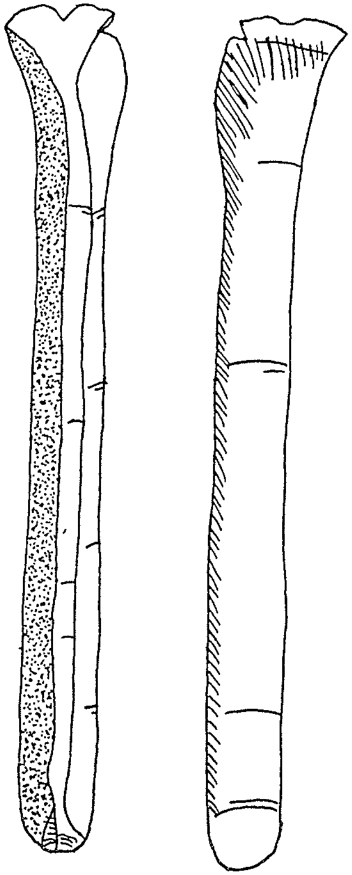

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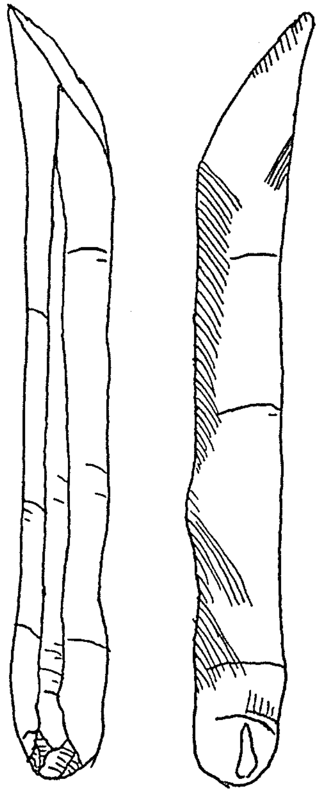

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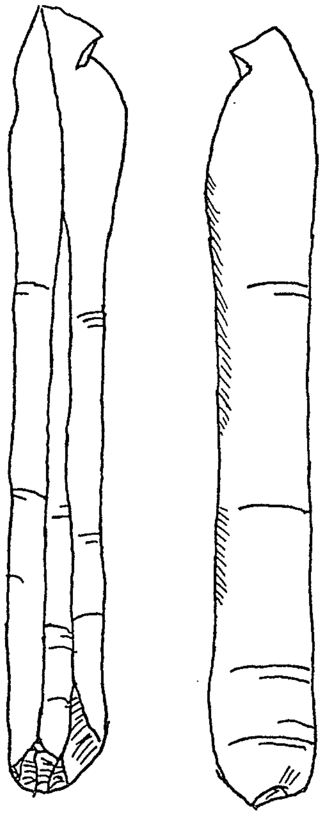

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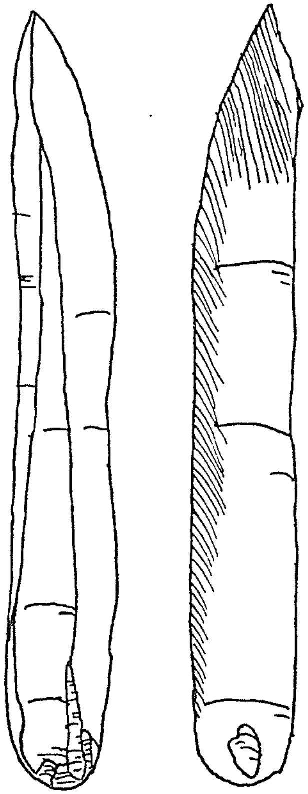

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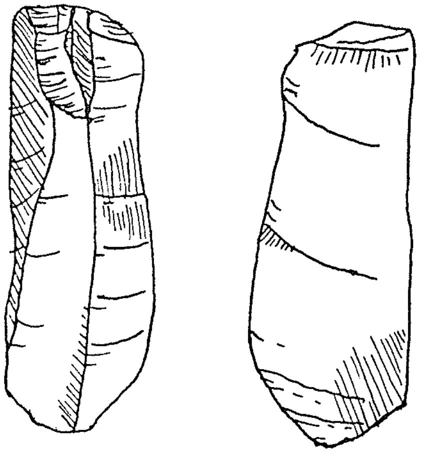
BLADE-LIKE FLAKES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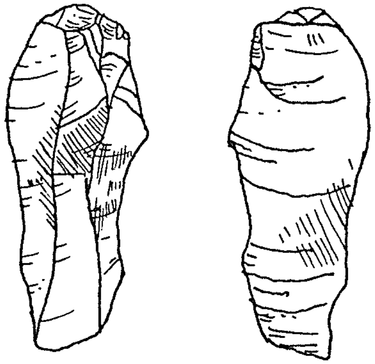
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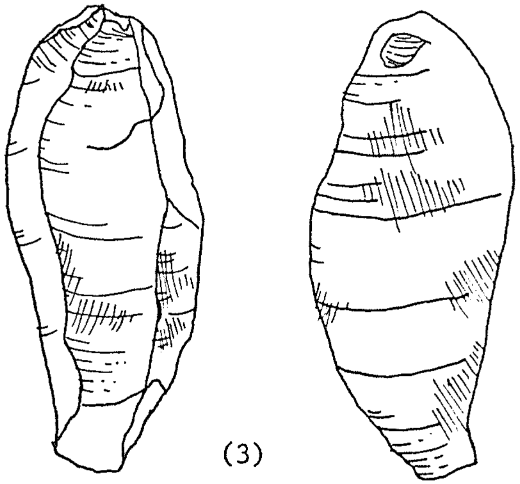
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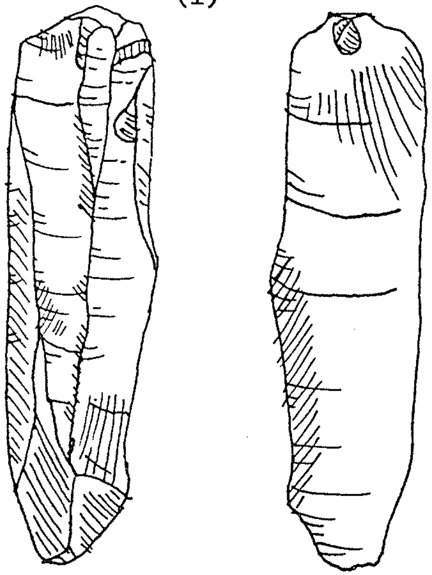
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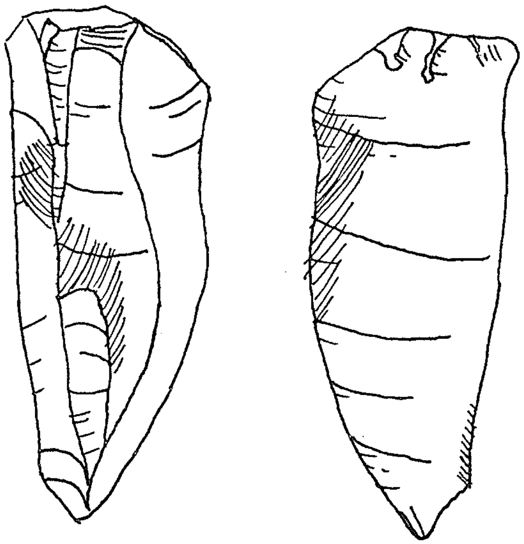
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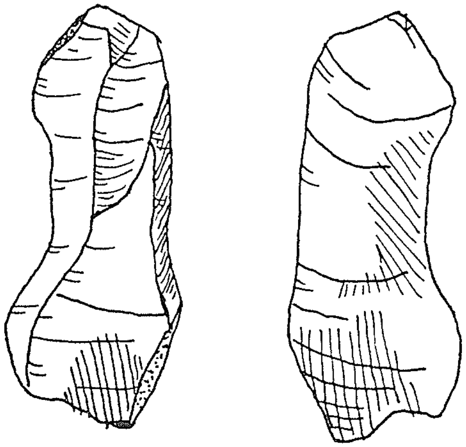
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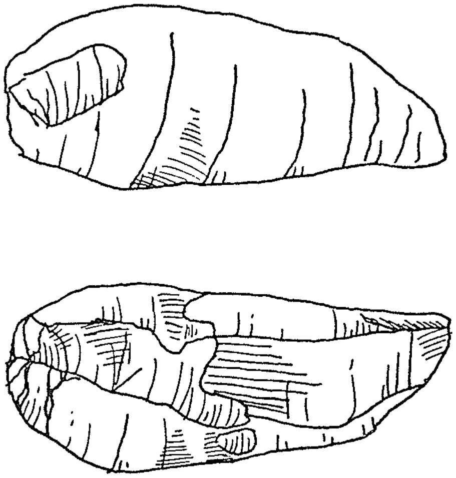
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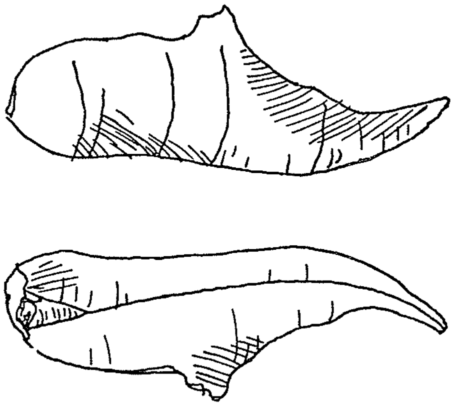
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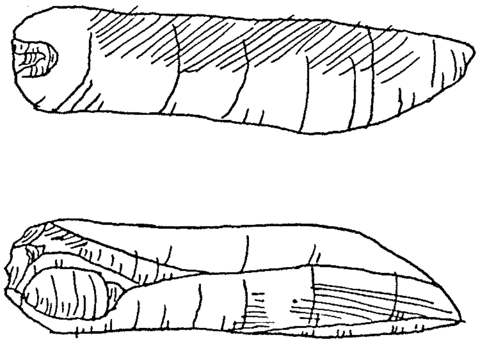
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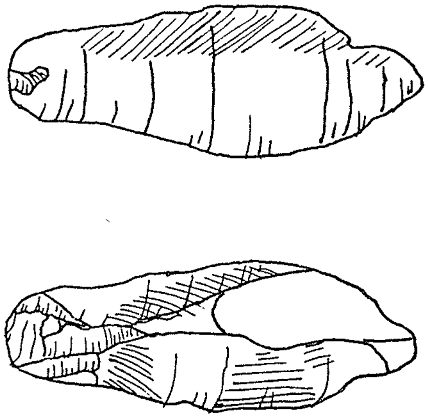
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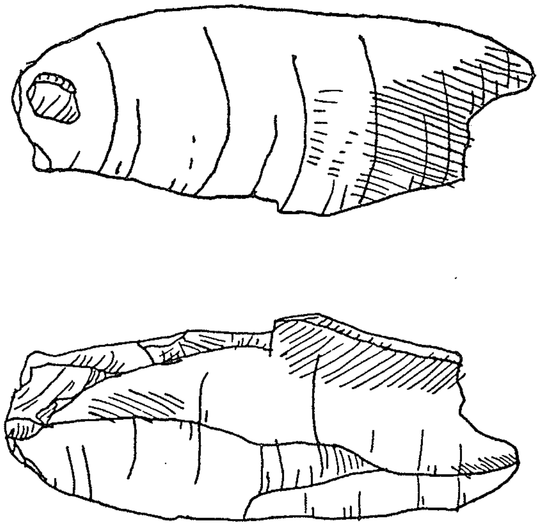
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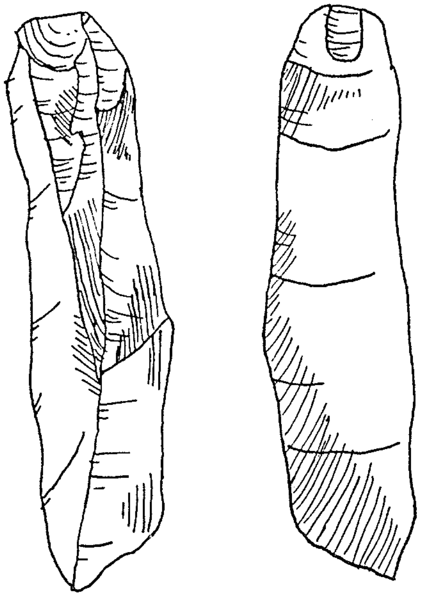
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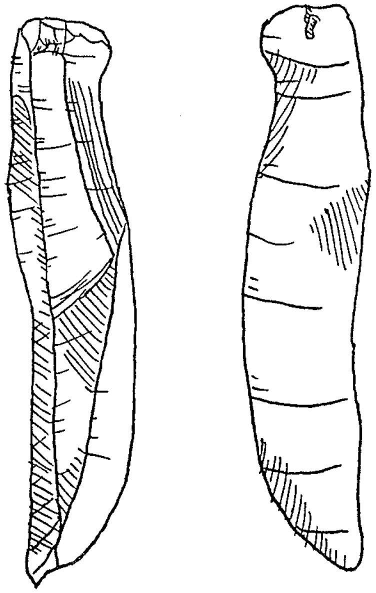
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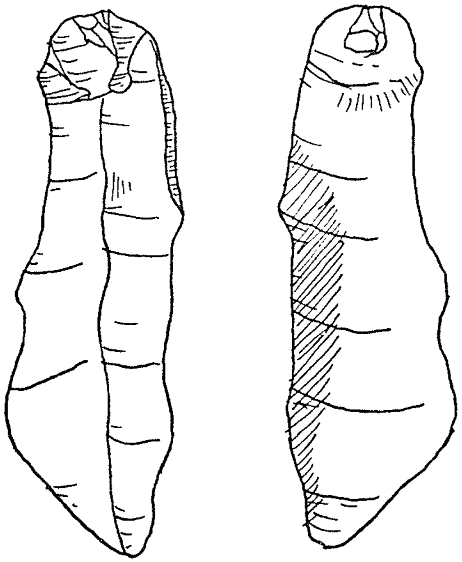
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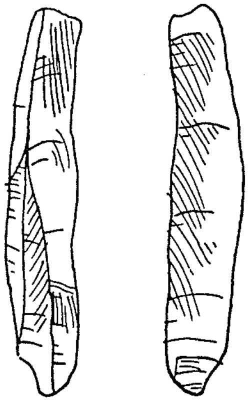
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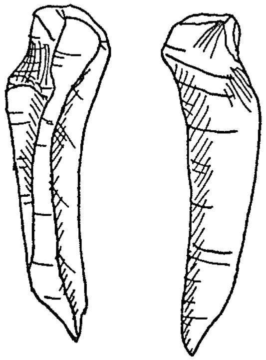
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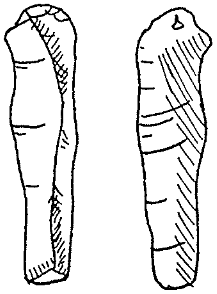
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