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ABSTRACT

This paper deals with the results of the author's attempts to replicate the obsidian polyhedral cores and prismatic blades of Mesoamerica. Blades have been produced by the direct percussion, indirect percussion, and pressure methods. The pressure method using a chest crutch and a clamp produces cores and blades which are true replicas of aboriginal specimens. The importance of preforming the core and of platform preparation is stressed, and it is pointed out that, usually, actual removal of the blade offers few problems. However, to produce exhausted cores which show the perfection of aboriginal specimens and a large series of nearly identical blades requires good muscular coordination, high quality material, the establishment of patterns or rhythms of motor habits, and the absence of distractions. The author also discusses the difficulties of recovering from mistakes in manufacture.

High-speed photography of prismatic blade removal, at 5,000 frames per second, has helped illustrate the behavior of the material and of the stoneworker. These photographs also indicate that under the present experimental and photographic conditions the author (Crabtree) is able to remove a prismatic blade from a core in about 1,250th of a second.

THE POLYHEDRAL cores of Central America represent a distinct type of cylindrical core, and their shape is the end result of the techniques used to remove prismatic blades vertically from the perimeter of the core. These cores reveal a technique and a degree of refinement different from any other core type, and the cutting quality of the prismatic blades is unexcelled. In size, the cores range from 1½ to 8 in. in length, and some are probably even smaller or larger. The prismatic blades are compatible in size, lessening in length as the core grows progressively smaller. Although the exhausted core is an interesting object of study for archaeologists, it has never played a really important part in the tool industry other than providing evidence of use as an anvil, the midsection sometimes modified into an ear plug, and occasionally indicating use as a reamer (Fig. 1).

Interpreting the manufacturing techniques of these cores and blades has been a challenge to the writer for many years, and it has resulted in numerous experiments with various methods of manufacture. I do not feel that I have resolved all the problems which confronted the workers of the past, but I have succeeded in producing cores comparable to those made by the people of Mesoamerica. The observations of Torquemada on seeing the early Americans use the crutch method to produce these prismatic blades have been invaluable to my experiments. However, he either failed to record the details that would be important to the stoneworker, or he has been misquoted by his translators. I find it impossible to produce blades in the manner he purportedly described. Translations of his observations were made by Sir E. B. Tylor (1861), and it is certainly possible that they have lost something in the translation. Words like "bending" may have been translated as "sitting," for I find it improbable, and highly impractical, to remove prismatic blades in a sitting position and under the conditions described. I do, however, feel that the sitting position needs further study and experimentation for, if it can be proved workable, it would have certain advantages. For instance, the standing position allows the blades to be driven into the ground whereas the sitting position would place the core parallel with the ground; therefore, the blades would hit the ground with less impact, and this would decrease the amount of breakage.

We are fortunate in having a recorded observation of this technique, and it is well that we review and analyze the historical writings and observations of Torquemada, Sellers, Catlin, Joly, and Hernandez. According to the Spanish Franciscan Friar, Juan de Torquemada (Holmes 1919: 323–4),

> They had, and still have, workmen who make knives of a certain black stone or flint, which it is a most wonderful and admirable thing to see them make out of the stone; and the ingenuity which invented this art is much to be praised. They are made and got out of the stone (if one can explain it) in this manner: One of these Indian workmen sits down upon the ground and takes a piece of this black stone, which is like jet, and hard as flint, and is a stone which might be called precious, more beautiful and brilliant than alabaster or jasper, so much so that of it are made tablets and mirrors. The piece they take is about eight inches long, or rather more, and as thick as one's leg or rather less, and cylindrical. They have a stick as large as the shaft of a lance, and three cubits, or rather more, in length, and at the end of it they fasten firmly another piece of wood eight inches long, to give more weight to this part, then pressing their naked feet together, they hold the stones as with a pair of pincers or the vise of a carpenter's bench. They take the stick (which is cut off smooth at the end) with both hands, and set well home against the edge of the front of the stone, which also is cut smooth in that part; and then they press it against their brest (*sic*), and with the force of the pressure there flies off a knife, with its point and

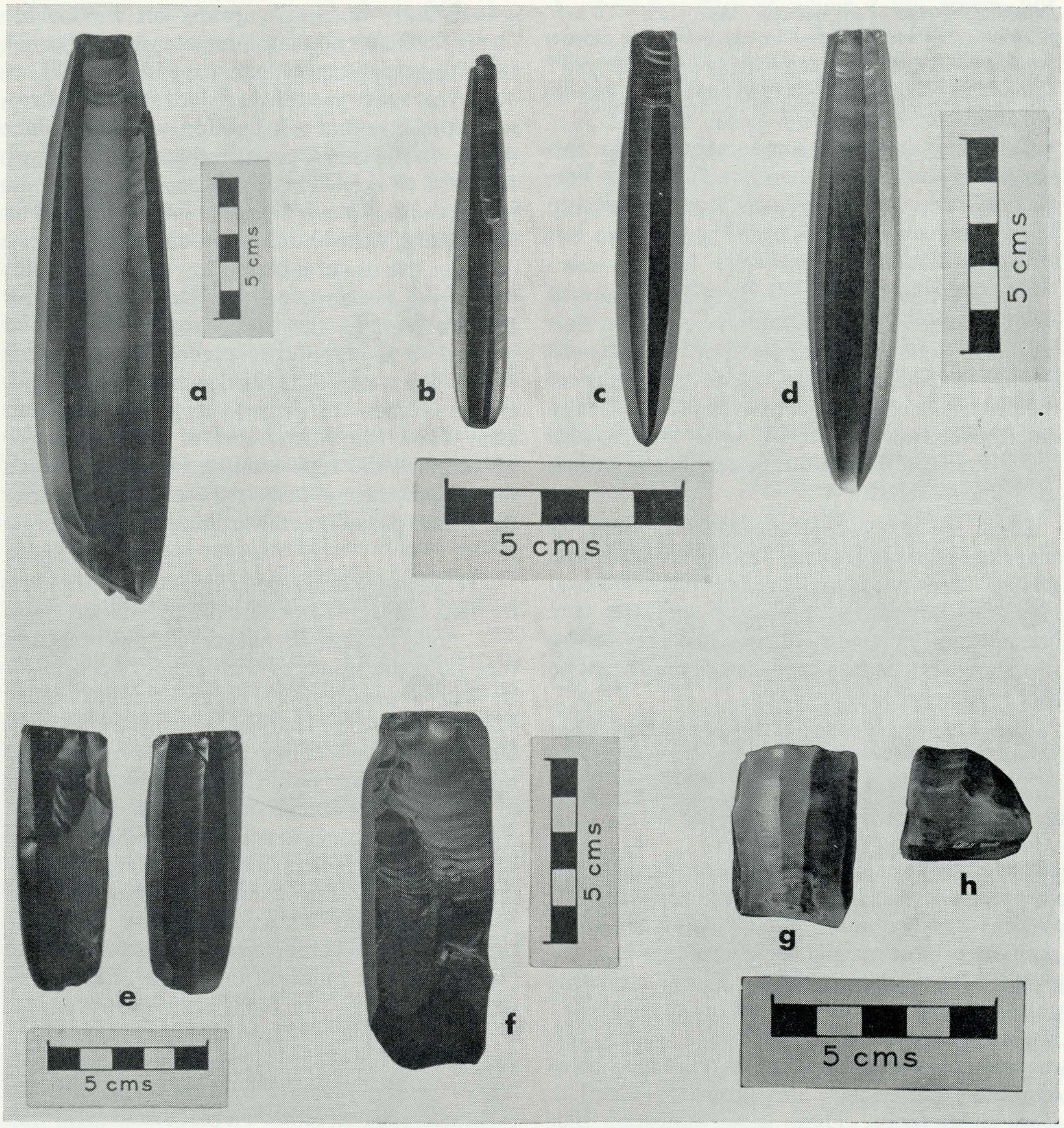


FIG. 1. Aboriginal cores. *a*, large obsidian polyhedral core from Colima, Mexico (I.S.U.M. Cr 1076); *b*, obsidian polyhedral core from Puebla, Mexico (I.S.U.M. Cr 1077); *c*, obsidian polyhedral core from Taxco, Mexico, (I.S.U.M. Cr 1079; notice on *b* and *c* the step fractures [angular breaks] from last attempts to detach blades); *d*, obsidian polyhedral core from Teotihuacán, Mexico (I.S.U.M. Cr. 1078; note the perfect termination of all blade scars); *e*, (I.S.U.M. Cr 1081) and *f*, (I.S.U.M. Cr 1080) obsidian cores from Teotihuacán, Mexico, showing blade removal on one side and original cortex surface on the other side of the core; *g*, blade surface (negative scars of previously detached blades) and *h*, platform surface of a small rectangular Hopewellian blade core from Ohio (I.S.U.M. Cr 1167).

edge on each side, as neatly as if one were to make them of a turnip with a sharp knife, or of iron in the fire. Then they sharpen it on a stone, using a hone to give it a very fine edge; and in a very short time these workmen will make more than twenty knives in the aforesaid manner. They come out of the same shape as our barbers' lancets, except that they have a rib up the middle, and have a slight graceful curve toward the point. They will cut and shave the hair the first time they are used, at the first cut nearly as well as a steel razor, but they lose their edge at the second cut; and so to finish shaving one's beard or hair, one after another has to be used; though indeed they are cheap, and spoiling them is of no consequence. Many Spaniards, both regular and secular clergy, have been shaved with them, especially at the beginning of the colonization of these relms (*sic*), when there was no such abundance as now of the necessary instruments and people who gain their livelihood by practicing this occupation. But I conclude by saying that it is an admirable thing to see them made, and no small argument for the capacity of the men who found out such an invention.

Certainly there are some inequities in this statement and, rather than conclude that Torquemada was a poor observer, I am inclined to believe that much of his meaning has been lost in the translation. For example:

(1) We now know that these blades are of obsidian whereas the translation observed that the black stone is as hard as "flint." This could be due to Torquemada's lack of knowledge of the properties of stone or to his desire to be more descriptive; however, if we were to take this literally, it could be quite misleading regarding the lithic material.

(2) If the text is carefully studied, one notes that the observation of the "Indian sitting on the ground" does not actually relate to the removal of blades but rather, I suspect, indicates core preparation. For we note that just previous to this statement he has been describing the stone and

. . . they are made and got out of the stone in this manner: One of these Indian workmen sits down upon the ground and takes a piece of the black stone . . . about eight inches long, or rather more, and as thick as one's leg or rather less and cylindrical (Holmes 1919: 323–4).

Clearly he is talking of core preparation for the normal core is about 8 in. long and about as thick as one's leg and is cylindrical and the sitting position is most normal for core preparation — establishing ridges, straightening ridges, grinding platforms, etc. The phrase "got out of the stone" I would interpret as meaning the worker was removing from a large block of obsidian a piece of stone large enough and properly shaped to serve as the core. There is no indication that Torquemada was referring to the sitting position for blade removal by pressure, and my experiments have resolved, for me, that this position will simply not permit enough leverage to remove blades of this size and shape. When the worker is in a sitting position he can only apply pressure from the shoulders, and this amount of force is insufficient to remove a blade. Also he is in an awkward position for seating his tool properly, and, as he lowers his chest for the thrust, his knees would necessarily be lifted up, which would lessen the hold of the naked feet on the core and, therefore, would change its angle and lessen its stability. If the worker were seated with his back against an immovable object, such as a tree or large stone, he could exert great pressure by extending his arms. However, the arms are also needed to provide upward pressure and not just for pushing straight down. In the sitting position this would be away from the worker. The sitting position also limits the amount of movement that can be exerted by just flexing the shoulder muscles. Even if we consider the use of a clamp in conjunction with the sitting position, we still cannot make this position feasible; the clamp would have to be secured to the ground to prevent its sliding. If the worker were in the sitting position, he would, at the moment of thrust, just push the clamp away from him. Any sort of holding device necessitates the repositioning of the core each time a new face is to be exposed, which makes the sitting position awkward and highly impractical.

(3) Torquemada's description of the holding method I also question, for the translation states ". . . they press their naked feet together, and they hold the stones as with a pair of pincers or the vise of a carpenter's bench" (Holmes 1919: 324). Suppose we change one word in this text; we could have: "They press their naked feet together and they hold the stones as with a pair of pincers *and* the vise of a carpenter's bench." This certainly concurs with my experiments and with Catlin's (Sellers 1886: 874) later description of the vise. I do use a crude holding device much resembling a carpenter's vise, and I do press my feet together against the core such as "with a pair of pincers." My experiments have definitely proven, for me, that it is impractical, if not impossible, to sit on the ground, hold the core with the naked feet, and remove prismatic blades by the pressure method. The outward force necessary to remove a blade is so great that no degree of muscular development would suffice to immobilize the core sufficiently to accomplish removal. Any movement, however slight, will cause the blade (and all subsequent blades) to be ill-formed or broken, before it has left the core, thereby making the core unfit for further use. Aboriginal cores are mute evidence of their immobility during manufacture, for they are far too perfect and the flake-scars show too few undulations to have been held by the feet alone. Since the outward pressure is almost as great as the downward pressure, one must not only stand on the holding medium (for stability) but, if the core is extremely large, it must be

further secured by the use of weights (heavy rocks or something similar) on the clamp. Further, I believe everyone is familiar with the sharpness of obsidian, and even Torquemada attests to this in his description of the cutting edge. A preformed polyhedral core must have established ridges which can be very sharp (covered in detail later in this text), which makes holding the core with naked feet very dangerous. Picture, therefore, the aborigine seated with this sharp-ridged core pressed firmly enough between his naked feet to hold it secure for the pressure removal of blades, and you have an aborigine with badly cut, badly bleeding, feet. Even placing woven mats or some other substance between the feet and the core would not prohibit the cutting, for obsidian will penetrate hide, skin, leather, mats, and just about any material that could be used to assist in holding the core. I believe the misconception of the sitting position and the feet holding the core is the result of an artist who made his sketch after a casual reading of the source. I have seen a very early drawing of this method in a German text (Jacob-Friesen 1949) showing the worker seated flat on the ground with feet outstretched, holding the core "pincer-like" between the feet and casually removing blades. Referring to *B.A.E. Bulletin* 60, page 323 (Holmes 1919), we now find the worker seated on a boulder, in a semistanding position, with a shortened crutch, but still holding the core with the naked feet. But in *Flint-Working Techniques* (Ellis 1940: 47) we have a drawing of the worker standing, though the text still contains the same description for removing blades while in a sitting position.

(4) "Then they sharpen it on a stone, using a hone to give it a very fine edge . . ." (Holmes 1919: 324). If we casually read the text, it would seem that Torquemada is stating that the aborigine sharpened his prismatic blade. We know this cannot be true for this very intricate method of blade removal was invented by the aborigine for the express purpose of giving a long, thin blade with an edge that is infinitesimal. Therefore, why hone it? Also, archaeological evidence reveals no abrasion of the edges of these blades that would indicate honing. On analyzing the text, I conclude that he is either referring to the worker sharpening the tip of the crutch tool or honing the top of the core for the platform preparation. Personally, I believe the reference is to sharpening the tip of the crutch for this is a very necessary part of blade removal. This reference is made in conjunction with the "stick" which would seem to indicate sharpening of the tool tip.

> They take the stick with both hands, and set well home against the edge of the front of the stone, which also is cut smooth in that part; and then they press it against their brest (*sic*), and with the force of the pressure there flies off a knife. . . . Then they sharpen it [tip of crutch] on a stone using a hone to give it a very fine edge; and in a very short time these workmen will make more than twenty knives in the aforesaid manner (Holmes 1919: 324).

Unfortunately, his description of the blade, inserted between these two explanations, would lead one to attribute the honing to the prismatic blade, which certainly would be unnecessary. It is unfortunate that he did not record the material used in the tip of the crutch, for just a sharpened wooden stick would not be sufficient to remove these blades. If the wood were hard enough, it could suffice; but for my experiments, our local hardwoods are much too soft to withstand this concentrated pressure. They merely crush and splinter and serve no purpose for blade removal. It is possible that the prehistoric workers used antler, bone, or jade for this tip, but we have no documentation for this other than that the proximal ends of their blades indicate that less than one-eighth of an inch of surface was contacted by the distal end of the pressure tool, indicating a tip of material harder than wood.

(Since the writing of this paper, I acquired some very hard wood from Mexico — variety unknown; consequently, I made an additional experiment of detaching a prismatic blade with a wooden staff minus a metal or antler tip. Because of the limitation of time, I have, to date, only removed three blades in this manner. I seated the rounded distal end of the chest crutch directly over a ridge, applied a thrust of downward and outward pressure, and successfully removed several perfect blades. The blades are true replicas.

(Each time a blade is removed from the core a new position must be selected on the wooden tip, or the tip must be reworked to expose a new surface. In order to remove a blade from a core, the platform must be isolated so that just the platform area of the blade will contact the wooden pressure tip. The tip is not sharp, but it is very blunt in order to give it strength. At this time it is necessary to use the metal tip in conjunction with the wood in order to isolate a platform surface suitable for using the wooden tip. To make an entire polyhedral core by the use of the wooden tool alone will need additional experiments before it is fully resolved. This can be done when the exotic hardwoods, such as Sapodilla, Chonta palm, etc., are available.)

(5) "They have a stick as large as the shaft of a lance, and three cubits, or rather more, in length, and at the end of it they fasten firmly another piece of wood eight inches long to give more weight to this part . . ." (Holmes 1919: 324). It is a little hard to decipher the exact measurement of a "cubit" in 1615 for, even today, we have several meanings for a cubit. The Hebrew, Roman, and English cubits all differ, being from 18 to 22 in. in length. If we apply this measurement to the Aztec crutch, we would have a length of possibly 5 ft. 6 in., and, when we add to this the cross-piece Torquemada refers to, we would have a stick of about 6 ft. in total length. Presently, we think of a cubit as being the length from the elbow to the tip of the middle finger. In my case this would be 19 in. per cubit, and I would still end up with a crutch well over 5 ft. in length, which is much too long for employing this pressure method. The ideal crutch for me is about 32 in. long, but each worker will require a different measurement, depending on his height, and measuring the distance from the second joint of the first finger to the chest.

(6) "They will cut and shave the hair the first time they are used, at the first cut nearly as well as a steel razor, but they lose their edge at the second cut; and so to finish shaving one's beard or hair, one after the other has to be used . . ." (Holmes 1919: 324). This is hardly consistent with the description and praise of their fine cutting edge unless we can assume that the barber was very careless with the tool and laid it down on some hard surface or permitted it to rub against another blade. For the only thing that will dull this fine edge is letting it rub against another blade or hard surface, and, if they are carefully handled and wrapped to protect the edge, they will retain a keen cutting surface almost indefinitely. I have shaved myself many times with the same blade and have seen little or no use-scars on the edge. This last summer at the Archaeological Field School of the University of Arizona at the Grasshopper site, Gene Seeley, Apache Cattle Manager, skinned a bear with one of these blades, and, after the job was completed, we could see little or no dulling of the edge. It is conceivable, however, that these blades were so numerous that the barber was not concerned about ruining the edge and, therefore, used many of them for one haircut to insure against offending the Spaniards by hair-pulling while using a dull blade. Or perhaps when Torquemada said "but they lose their edge at the second cut," he was referring to the second time the hair or beard was cut.

Therefore, if we are to take the translated version of this Friar's observations verbatim, we have the picture of an Indian sitting flat on the ground, legs straight in front of him, holding a very sharp core between his naked feet, and pressing off blades with a crutch that measures well over 5 ft. This simply will not work, and I suggest that the reader convince himself of this by trying this method personally. I rather think the standing position, with core in a holding device and with the worker pressing on a shorter crutch, is the true picture.

I do not mean to infer that the sitting position and feet-holding methods are never used. I use this many times to produce other types of artifacts, but not for pressure work. When I employ the use of my feet, I am generally using the indirect percussion method (see Indirect Percussion method, this paper).

According to Ellis (1940), Hernandez, in 1651, made a little more detailed observation of this technique and added that the worker used a hard stone on the obsidian core before he applied the wood presser. He reasoned that they were removing angles from the edge and the platform before removing the blades. Coutier and Barnes (Barnes 1947), quite correctly, deduced that the stoneworker scratched the platform of the core with a rough stone to abrade the surface and to prevent the tip of the pressure tool from slipping.

G. E. Sellers recorded the observations of Catlin, who lived with the North American Indians and observed their blade manufacture (Sellers 1886: 874):

> In some cases the stone operated on was secured between two pieces or strips of wood like the jaws of a vise, bound together by cords or thongs of rawhide; on these strips the operator would stand as he applied the pressure of his weight by impulse. . . . The tool used being a shaft or stick of between two and three inches diameter, varying in length from thirty inches to four feet, according to the manner of using them. These shafts were pointed with bone or buckhorn, inserted in the working end . . . bound with sinews or rawhide thongs, to prevent splitting. For some kinds of work the bone or horn tips were scraped

to a rather blunt point, others with a slightly rounded end of about one-half inch in diameter.

Here we have a description of the vise and the crutch, which both replicate the equipment I use in my manufacture.

N. Joly (1883) gives a description of prismatic blade-making in his book *Man Before Metals.* His version (Joly 1883: 212) is quite different from both Torquemada and Catlin:

M. Courtes, member of the French Scientific Commission of Mexico, and M. Chabot, maintain that the Aztecs, in making their obsidian razors, begin by shaping the rock near the quarry when it was taken. Then after having given to it the form of a prism terminated at one extremity by a blunt point, at the other a flat surface, the workman takes his prism in the left hand, and pressing it against some resisting surface, strikes it at first with light blows, gradually increasing them in force until at last he obtains splinters as sharp as razors and destined to serve the same purpose.

This method could very well serve to make sharp flakes, but it could not possibly produce a replica of the polyhedral core of Mesoamerica. This description of manufacture would make little sense to any stoneworker, for if it were at first struck with light blows this would crush the stone and destroy any platform preparation; and increasing the velocity of the blows would remove a flake, but it would have multiple undulations and concentric waves which are not present on the prismatic blades. The tiny platforms found on the prismatic blades are testimony that they were removed by pressure and with repetition, accuracy, and uniformity. A comparison of blades removed by percussion and pressure will quickly prove this point. Obsidian has very little resistance to end-shock, and it is just not adaptable to removing long well-defined blades by the percussion method.

All of these records are valuable contributions to the recording of this technique, but they do differ in some respects, and I think one must analyze them and allow for translation discrepancies.

Dr. Robert Heizer's present investigation of a site in Guatemala where polyhedral cores are found will probably contribute much information about what tools were used and regarding the development and resolving of techniques of this particular blade industry. A surface collection from this site indicates methods of severing cores, core rejuvenation, use of exhausted cores as tools, aberrant core forms, and those discarded in various stages of manufacture. But, at the present time, there has been very little study or research published on the removal of prismatic blades from a polyhedral core.

The actual removal of prismatic blades from the core is not a difficult technique. The problem lies in preforming the core in the proper shape with ridges to guide the blades, and in the proper positioning of the tip of the crutch tool. Verification of this was manifest at the Lithic Technology Conference held in 1964 at Les Eyzies, when every participant was able to detach a satisfactory blade. Further, the largest and most perfect blade was removed by Dr. Denise de Sonneville-Bordes whose weight is well under 100 pounds, thus indicating that this technique also does not require tremendous strength. Each of the participants was given instructions and help in placing the tip of the pressure tool correctly on the platform, but the actual blade removal presented no problem for them.

Following is the record of my experiments with this technique which have produced true replicas of the polyhedral cores and prismatic blades.

Material: Since my experiments have been an effort to reproduce the obsidian Mesoamerican polyhedral cores, I have used, primarily, obsidian from Glass Butte, Oregon. It is found in many colors, textures, and qualities and is an excellent working material. The best quality from this area is that with an absence of flow structure, that found *in situ,* and that with homogeneity and glass-like qualities. However, I have also experimented with other materials such as crypto-crystalline varieties of quartz, flint, and glass (Figs. 9*a, b,* 6*b–d,* and 10). Obsidian, or similar materials, must be homogeneous, fine-grained (or vitreous), uniform in composition and texture, and free of internal stresses or strains. It must be devoid of inclusions, grain, or undetected flaws, for the slightest imperfection will hinge-off the blades and render the core useless for further blade removal. Fortunately for the men of prehistory, obsidian was found in abundance in certain areas of Mexico and Guatemala, and it appears that only that of supreme quality was selected for this blade industry.

All obsidian is not suitable for making polyhedral cores, though it may still be excellent material for the manufacture of a variety of other tool forms. Some obsidians are excessively brittle as a result of self-contained internal forces; this is indeed characteristic of the volcanic glasses that are geologically old. Others have imperfections (amygdaloids of crystobolite, Fig. 9c) because the obsidian had reached too great a temperature before it cooled. Many other factors are necessary for the formation of good obsidian. Color, or lack of color, appears to make little difference in workability of material; however, the presence of flow structure does cause differential resistance to applied pressure, resulting in irregularities on both the core and the blades. Even a minute imperfection can cause the pressure platform to collapse, or it may stop short the removal of the blade along the face of the core before it is removed in its entirety. This creates either a step or a hinge fracture. When this occurs, additional flakes or blades cannot be removed as too great a mass of material remains on the face of the core, and in most instances it must be abandoned.

Obsidian appears to have the properties of a solid, yet it behaves in the manner of a heavy liquid. In order to make blades or any other artifact, the maker must be able to control the wave mechanics of this most viscous material. The waves and undulations must be eliminated before a true blade may be removed from a core. A study of the wave patterns on cores and blades may reveal much regarding the techniques of manufacture. Considerable research and study are still necessary to understand the character of a solid which retains the behavior of a heavy liquid, and to control such a solid when subjected to force. My experiments have helped me develop techniques for working with such materials and have permitted control of this phenomenon which I call "wave action." When making blades and cores, I have used only body strength, but if these same fractures could be studied under laboratory conditions with the aid of a mechanized device, we might analyze mathematically the forces involved.

Crutch: The tools used in prismatic blade manufacture are the chest crutch and the holding device. The crutch I use is about 32 in. long, but the length will depend on the individual worker's stature. The length is determined by measuring the distance between the tip of the index finger and the chest. Place the shaft on the chest, bend over, and place the tip of the shaft on the platform of the core. It is important that the crutch be no longer than the lengh indicated above (tip of index finger to chest) as the index finger must place and guide the tip of the pressure tool to the exact position on the edge of the core.

The shaft must be thick, but not so large as to be cumbersome and to impair the line of sight between the worker and the top of the core. My crutch has been made from a heavy-duty shovel handle and has served the purpose very well. The wood must be semi-inflexible, for any quivering of the shaft will cause the blade to undulate as it tears loose from the face of the core. This will cause irregularities on both the blade and the core which cannot be overcome with subsequent blade removal.

A pointed piece of antler, ivory, bone, or metal is affixed at the end of the staff, secured by a ferrule or serving, to hold it tight. This immobilizes the tip of the pressure tool and also prevents the shaft from splitting. The tip is made flat on the side facing the worker, and the opposite side is rounded to give it strength. The tip will resemble the point of a screwdriver with the outward side slightly rounded — much like a "U" with the top of the "U" facing the worker. This shape prevents the tip from dragging on the edge of the core, which would cause the edge to crush. If the tip is rod-like with the point in the center, it will sometimes catch on the edge of the core and crush the platform. After use, the tip must be checked for adhering particles of obsidian, which will also cause the platform to crush. Using a copper tip eliminates the continual resharpening that is necessary with other materials.

The proximal end of the crutch is fitted with a short flat piece of wood, shaped to the size and comfort of the worker, which will serve as a chest rest. The chest crutch now resembles a capital "T," the top part of the "T" being the part placed against the chest.

This type of crutch is not only useful for the removal of prismatic blades, but it is also used to remove the channel flakes from points such as Folsom and Clovis and may be used for the final retouch on large bifacial artifacts. The crutch allows the worker to place the tip of the pressure tool on the platform with extreme accuracy and precision and permits him to apply controlled pressure in variable degrees.

If the crutch is employed to remove large blades by the combination of the pressure and percussion technique, then a piece of hardwood about 4 in. long is affixed to the staff near the tip to serve as a striking medium; one worker applies the blow when another person applies

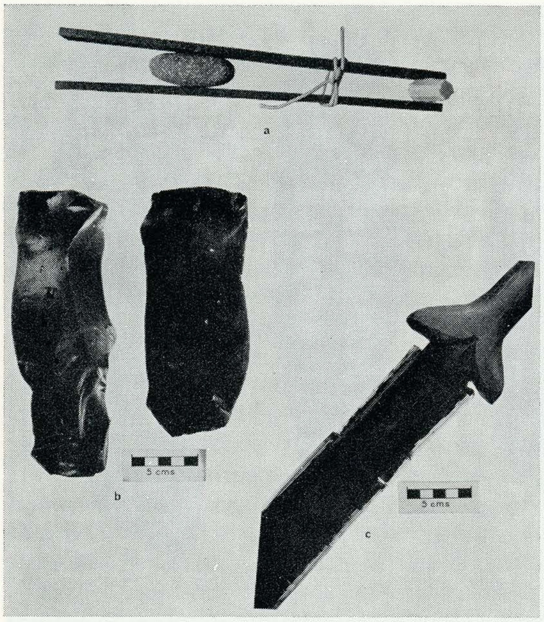


FIG. 2. *a*, clamp used to hold cores for removal of flakes and blades by indirect percussion or pressure; *b*, front and back surfaces of two very large obsidian blades produced, by Don Crabtree and Gene Titmus, by a combination of indirect percussion and pressure (I.S.U.M. Cr. 1185); *c*, replica made by Crabtree of a Mesoamerican wooden sword with obsidian prismatic blades hafted along the edges showing one of the many uses of prismatic blades.

the pressure. If one is fortunate enough to find a young sapling to serve as a crutch in this operation, then he can saw off a limb near the tip of the staff to serve as the crotch for the striking medium. The striker, or percussion implement, is a billet of hardwood or a section of antler, about 14 in. long. Downward and outward pressure is applied, simultaneously, by one person with the blow delivered by a second person.

Vise: The core must be affixed in some manner, and I have experimented with every conceivable type of holding device, including the modern carpenter's vise, rack sticks, tourniquets, and even levers. None served as well as a homemade type similar to what prehistoric man could have devised. The most successful clamp, and the one most closely resembling that of the aborigine, has been two poles, or two 2 x 4 pieces of lumber, tied loosely together at one end with nylon cord. This allows one to slide the core in either direction to provide a variable fulcrum. The core is placed between the two shafts near the tied section. The opposite ends are spread, and a large cobble is inserted between the poles and slid up toward the core-holding end until sufficient pressure is obtained to make the core immobile. This clamp can help further to secure the core if several large flat slabs of stone are placed on the far end. The clamp now looks like a capital "A" with the core at the apex of the "A" (Fig. 2*a*).

The holding device must be immobilized in order to remove blades repeatedly, for the angle of the core in the vise is so critical that any movement or change of position will result in the worker breaking the blade before it has been entirely removed from the core. When this happens, the core must usually be abandoned.

Using the feet alone to hold the polyhedral core and at the same time to press off blades is impossible because the feet would allow movement of the core, and, to remove prismatic blades, it is essential that both the core and the vise be immobile. Prismatic blade removal requires the worker to use the weight of the body and also to assist with pressure from the knees. Therefore, with all this body movement, it would be most difficult to secure a core by the use of the feet alone. Also, the holding device must exert a great amount of pressure to hold the core securely, due to the amount of outward pressure exerted by the hands when detaching a blade. In fact, the core should be slightly imbedded into the wooden jaws of the clamp.

The feet do play a part in this technique, but only for standing on the holding device to give it added weight and to insure against the clamp moving.

The beautiful prismatic blades removed from the polyhedral core have parallel sides which feather out to an infinitesimal edge, making them not only fine for a variety of cutting tools but also a formidable weapon. Freshly struck, they are unexcelled as cutting tools, without further modification. To protect the user's hand, they can be served or wrapped with maguey fiber, sinew, or thongs at one end in a manner similar to an authentic tool shown to me by Dr. Richard MacNeish. They will serve any cutting purpose, provided the nature of the material to be cut will not cause the edges to break (i.e., hard materials such as bone, stone, hardwoods, etc.). Cordage, fabrics, leather, textiles, flesh, hair, and other pliable materials may be cut by little pressure and with much ease. These prismatic blades can be converted to a backed blade by removing a series of small flakes on one edge to make it dull or abraded, or they

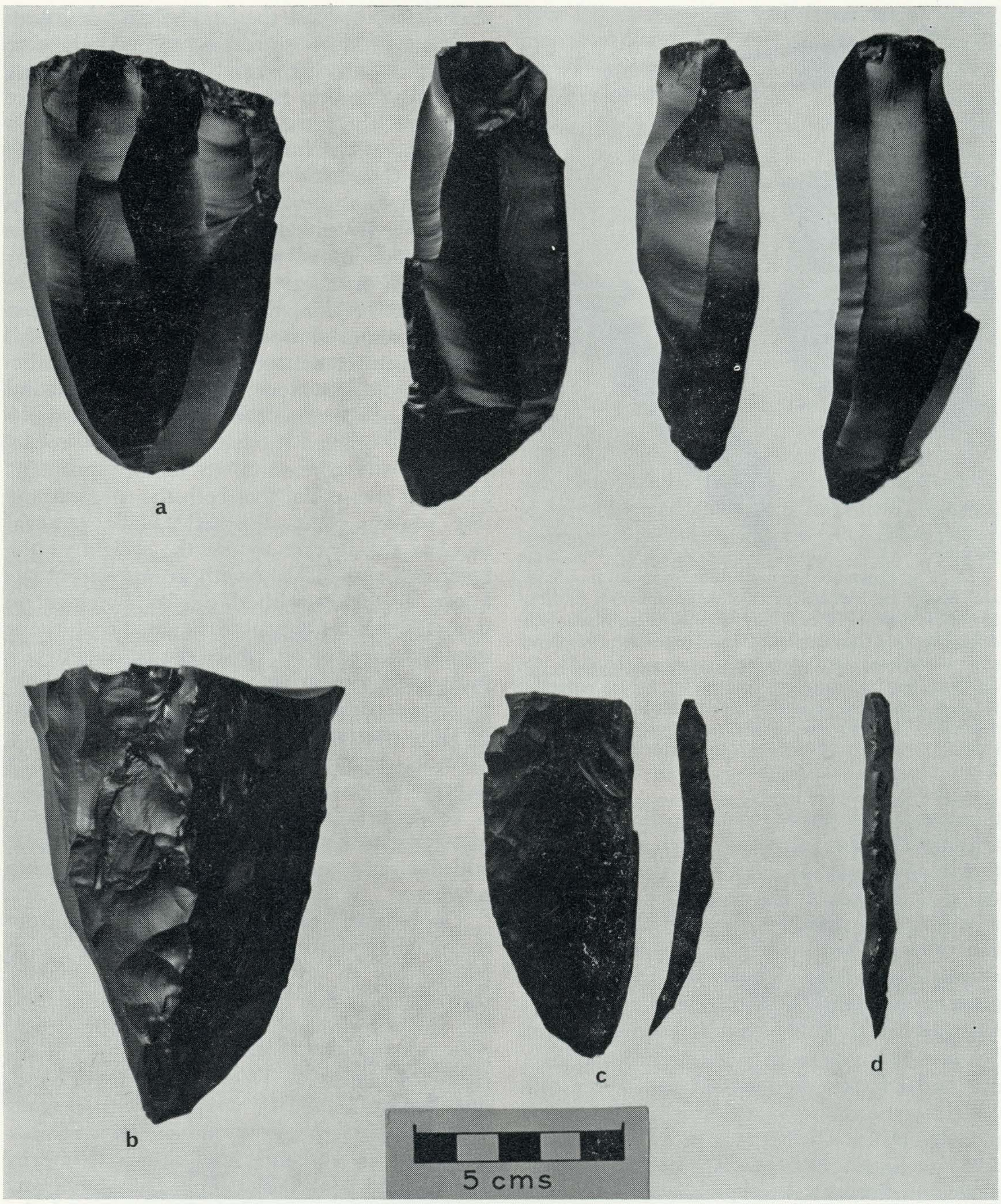


FIG. 3. Blades produced by indirect percussion, and core resulting from this technique, with ridge preparation and removal of the first blade; work done by Crabtree. *a*, blade core and three blades of obsidian produced by indirect percussion (I.S.U.M. Cr 1106; notice the general irregularity of the blade margins, the large bulbs of force on the core, and the very prominent undulations and ripple marks [compression rings?] on both the core and the blades); *b*, obsidian core preform showing the flaking done to prepare and straighten a ridge to guide and form the first blade removed from a blade core (I.S.U.M. Cr 1096); *c*, side view of an obsidian tongue-shaped core and the first blade (I.S.U.M. Cr 1159; note that the core shows evidence of several step-fractures and also the curvature of the blade); *d*, front view of the first blade shown in *c* illustrating the flaking done to produce and straighten the ridge.

can be hafted in the manner of a doctor's scalpel. Further, they can be worked into geometrics and inserted in various holding devices to suit the user's needs. When these sections, or pieces, of sharp blades were inserted in the edges of wooden swords or lances, they were, indeed, a functional and superior weapon (Fig. 2*c*).

During manufacture, however, these blades tear away from the core with considerable velocity, and, if they strike against each other or hit any hard substance, they will break or lose their sharp edge. Therefore, during manufacture, a soft landing spot or catching device must be provided. For catching blades, I use a mat of polyethylene foam, sponge rubber, or a soft woven grass mat. For transporting or storing, they must be kept separated, or wrapped individually. This necessary protection of edges may explain the wide distribution of utilized cores, for it would be much easier to transport a preformed core to the place of utilization than to make several hundred blades at the source of material and then transport them to the occupation site.

Prismatic blades have two main types of transverse section; those that are triangulate and, the more common, those which are trapezoidal in section. The sides of the blades are characterized by their very acute angles. Blades that are triangulate in section have a longitudinal ridge that extends in a median line from the proximal to the distal end of the blade (Fig. 3*c*, *d*). On the dorsal side of the blade and on either side of the medial ridge, there are remnants of the two previous blade-scars which leave a slightly concave surface, producing what is known in present-day cutlery as "hollow grinding." The ventral surface of the blade (the side next to the core) is slightly convex, which results in a blade with an extremely sharp edge. This feature is also present in a blade that is trapezoidal in section. However, trapezoidal blades, instead of having a single ridge, have two ridges to guide the flake, thereby making a flat surface with two beveled edges on the dorsal side (Fig. 7*a*). These ridges are the remnants of three previous blade-scars. This type of blade is, by far, the most common; this is perhaps because, functionally, it would make a deeper cut, for the blade is flatter and has a more acute angle than the triangulate blade. There are many aberrant forms of blades, depending much on the surface from which the blades are removed and also on the skill of the worker.

Polyhedral cores have numerous variants and do not have to be necessarily cylindrical in section (Fig. 1). At the Museo de Antropología Nacional in Mexico City, I saw much evidence of blades removed from just one side of an irregular piece, or pebble, of obsidian. Evidently the worker had found a piece of stone with natural ridges and had simply removed blades from one side of the stone. The final shape of the discarded core tells the story of the initial core preparation. It is not uncommon to find exhausted cores that still retain the original surface cortex on the base and on one or more sides, indicating that blades were removed from one or more faces of the preformed core but not around the entire perimeter (Fig. 1*e*, *f*). This suggests incomplete core preparation, or the use of naturally tabular pieces of obsidian.

Before a single blade can be removed from a core, a natural ridge of material must be found, or the worker must create such a ridge (Fig. 3*b*, *c*, *d*). If a round cobble of material is used, or just a large mass, then the worker must create this ridge by resorting to the percussion method and making the preform rectangular in shape. The ridge must be approximately at right angles to the platform face of the core and parallel to the long axis. If the percussion work has not established a ridge in this position, then the worker must straighten the ridge by removing a series of alternating short flakes along the vertical length of the material. These scars differ from retouch in that the force is applied at the body of the material outward from the median line, whereas retouch is directed from the marginal edge inward. Therefore, the first blade removed from the core will bear these retouch scars and will have very little resemblance to the common lamellar blade. It is interesting to note, at this point, that Holmes (1919: 225) has identified these large flakes as "slightly specialized for undetermined uses" and as "other interesting partially worked implements, the final shape of which could not be determined." Clearly these are the first blades removed from the polyhedral cores and are bearing the retouch scars. These first blades to be removed will be triangulate in section with multiple flake-scars directed away from both sides of the median ridge and at right angles to the longitudinal axis; the blade will have the appearance of a triangulate drill unifacially flaked. However, the bulbs of force of the preparing flakes will start at the center of

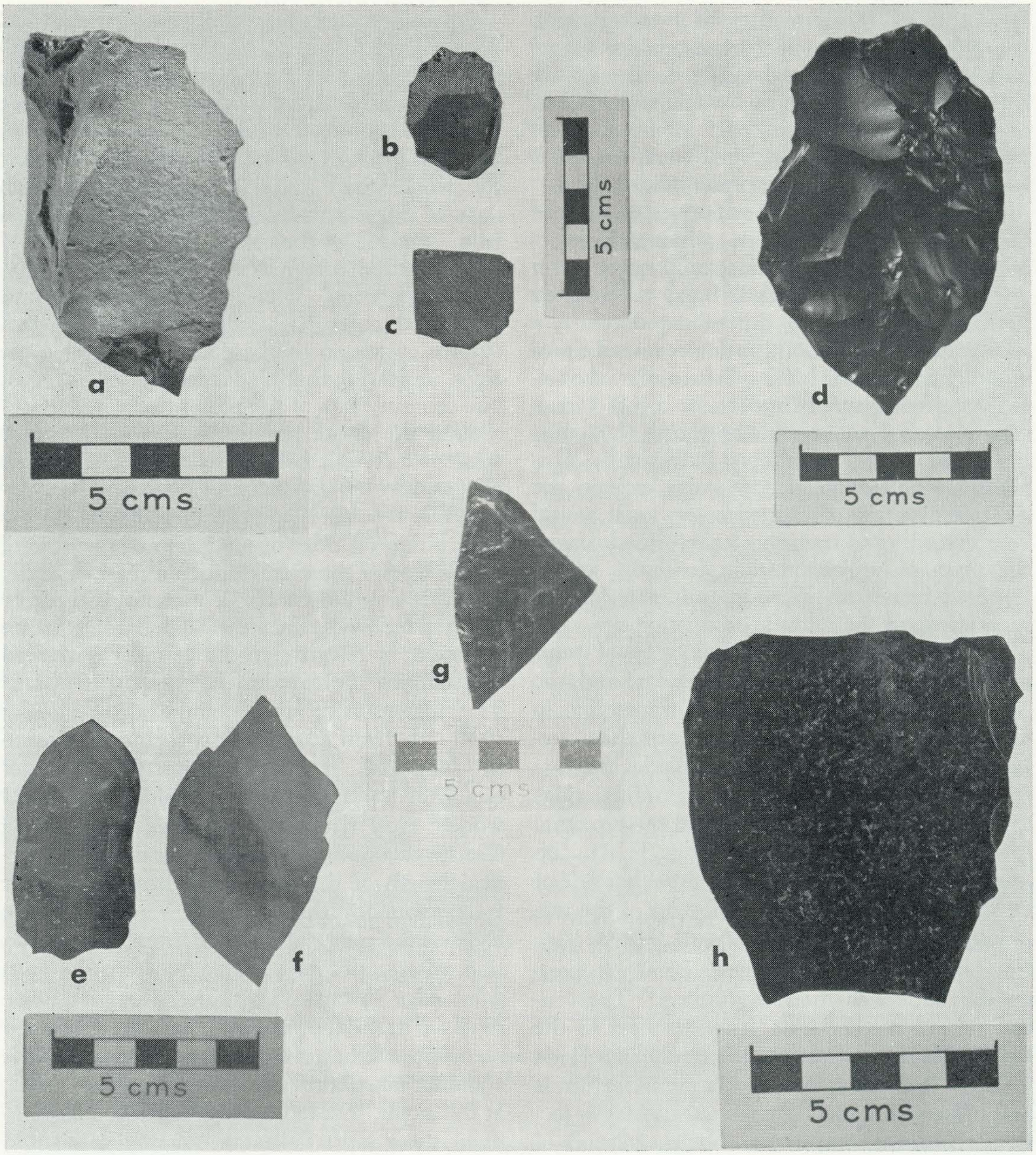


Fig. 4. Types of core preforms and platform surfaces. *a*, natural cortex platform (I.S.U.M. Cr 1169); *b*, flat flake surface with grinding or scratching on edge of platform (I.S.U.M. Cr 1118); *c*, ground platform (I.S.U.M. Cr 1119); *d*, multiple-flake platform (I.S.U.M. Cr 1104); *e*, single-ridge core preform of chalcedony with multiple-flake platform (I.S.U.M. Cr 1184); *f*, two-ridge preform of quartzite with flat flake platform (I.S.U.M. Cr 1172); *g*, three-ridge preform of obsidian with multple-flake platform (I.S.U.M. Cr 1173); *h*, four-ridge preform of obsidian with flat flake platform (I.S.U.M. Cr 1105).

the long axis and will be intersected when the initial blade is removed.

Removal of the initial flake leaves two ridges on the core, which are used by the worker to guide the next two blades. At this stage of making ridges to guide subsequent blades, occasionally another blade is taken off directly in back of the first to make the blades slightly wider. This is accomplished by removing the resulting overhang of the first blade removal and seating the pressure tool between the two previously established ridges. When this technique is used, the second blade will have the appearance of a functional tool for it bears the scars of the initial ridge-preparing flakes. On the dorsal side, blades will have a fluted, or slightly concave surface, which is the scar left after removal of the first blade.

Platforms: Platform surfaces are of five types:

1. platforms with a flat flake surface (Fig. 4*h*)
2. platforms left with a remnant of the bulb of a tiny flake which was designed and used to prevent the pressure tool from slipping (Fig. 4*d*)
3. platforms with a flat flaked surface with scratches put there by the worker to prevent the pressure tool from slipping (Fig. 4*b*)
4. platform of the natural flat surface, using the roughness of the cortex to prevent slippage (Fig. 4*a*)
5. platforms with the face of the core ground by abrasion to prevent slipping of the pressure tool (Fig. 4*c*).

The platforms of the prismatic blades are distinctive because they are normally at right angles to the longitudinal axis of the blade and because of the very small contact surface between the pressure tool and the core. Platforms are ground since this allows the flake to be freed from the core more easily. The bulbs of force (in this case, pressure) are normally diffused and quite flat. These bulbs are distinctive of pressure because of the absence of the eraillure flake usually found in percussion-struck flakes or blades. The curvature of the blades is somewhat variable because of the changes in angle in applying the pressure and because of the differences in the order of removal. Curvature increases as the core becomes progressively smaller for, as the core is utilized, the resulting overhang from the bulbs of pressure must be removed before the next series of flakes can be detached (Fig. 6*e* and 8*b*).

Preparing the edges for removal of each series of blades decreases the area at the top of the core; it becomes slightly smaller than the midsection, and, thereby, each successive series of removed blades is slightly more curved (Fig. 6*e*). The exhausted core becomes teardrop in shape with the pointed, or proximal, end indicating in which direction pressure was applied (Fig. 1*b*). As the proximal end of the core becomes more constricted, it is sometimes rejuvenated by removing the top with a single percussion blow that severs the core at right angles, and then it is ground by abrasion. Or, when the platform surface is exhausted, it is simply abandoned.

Another type of polyhedral core is made by changing the angle of applied pressure to produce a straighter flake or blade. This type of core is prepared in a slightly different manner. Initially, the distal end of the core is made smaller than the proximal end on which pressure is applied. As the core gets progressively smaller from blade removal, the distal end will become conical (Fig. 6*c*). When the area of the apex, or center, of the proximal end of the core becomes restricted, the distance between the proximal and distal ends lessens, and the blades become shorter; the core is then usually abandoned. Platforms on the blades will be slightly less than a right angle.

Upon abandonment, the core will still retain some of the top, or platform face, and will be tongue or bullet shaped.

Direct Percussion: My first experiments in polyhedral core making were by the use of simple direct hand-held percussion using a variety of percussion tools, and the results were most discouraging. The use of direct hand-held percussion allowed me to remove blades with some regularity, but the characteristics of the blades, or flakes, in no way resembled the classic prismatic blades (Fig. 5). Some observations concerning the use of this technique are as follows:

1. Blades detached by percussion were generally lacking in regularity of form.
2. They had too large a platform.
3. The bulb of percussion was much too large.
4. Multiple undulations on both core and blade resulted.
5. The distal end of the blades terminated with the tip of the core adhering.
6. It was impossible to keep the edges of the blades parallel.
7. The platforms collapsed from impact.
8. The intensity of the blow could not be controlled with accuracy, causing many step and hinge fractures.
9. The use of percussion on this core type does not permit the worker to place the percussion tool with the degree of accuracy necessary for blade removal.

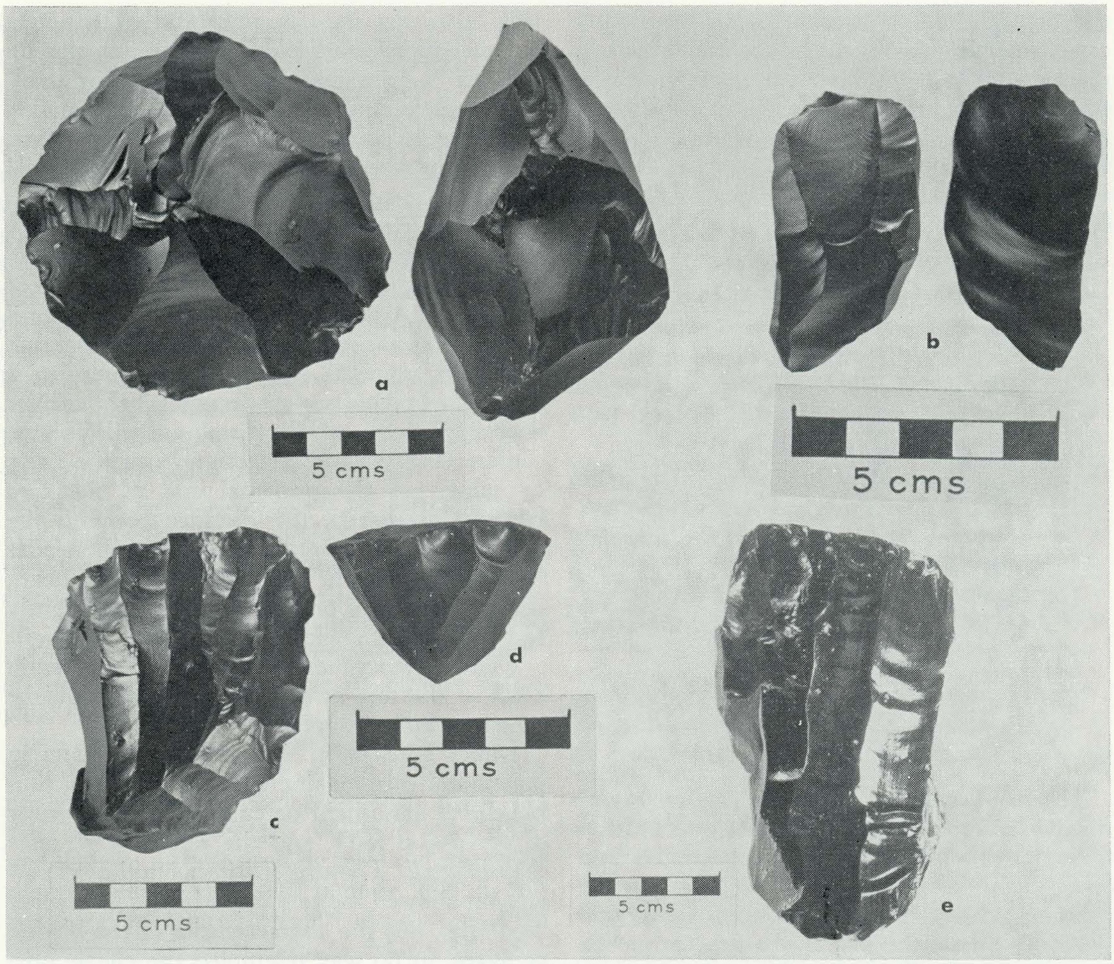


FIG. 5. Direct percussion cores produced by Crabtree. *a*, face view and side view of a biconical core of obsidian (I.S.U.M. Cr 1075); *b*, front and back views of a flake removed from *a*; *c*, bidirectional core of obsidian (I.S.U.M. Cr 1169); *d*, obsidian conical core (I.S.U.M. Cr 1168); *e*, large blade core of obsidian (I.S.U.M. Cr 1107; note the very prominent bulbs of percussion, the heavy undulations, ripple marks [compression rings?] and the general irregularity of all flake and blade scars).

10. The worker cannot simultaneously retain the same angle on the core and keep, in relation to the guiding ridge, the angle of the blow.
11. The proximal end of the core is reduced faster than the distal end because the overlap left from the large bulbs of percussion must be removed before the next blade can be detached.
12. The platforms on a typical aboriginal blade are normally $\frac{1}{16}$ of an inch, or less, in width. This degree of accuracy cannot be obtained by using a direct percussion technique. Should there be any deviation in size of platform and if it exceeds the tolerance of $\frac{1}{16}$ of an inch, the platform will collapse, or the blade will be unduly thick, or will terminate in a step or hinge fracture along the face of the core, making it worthless for further use.

Percussion is commonly used to remove blades from other types of cores but not from a polyhedral, and my experiments resulted in an exhausted core that in no way resembled the distinctive Mesoamerican types.

Indirect Percussion: Another experiment involved the use of indirect percussion. Tools used for experiments in indirect free-hand percussion have been of every conceivable type and mate-

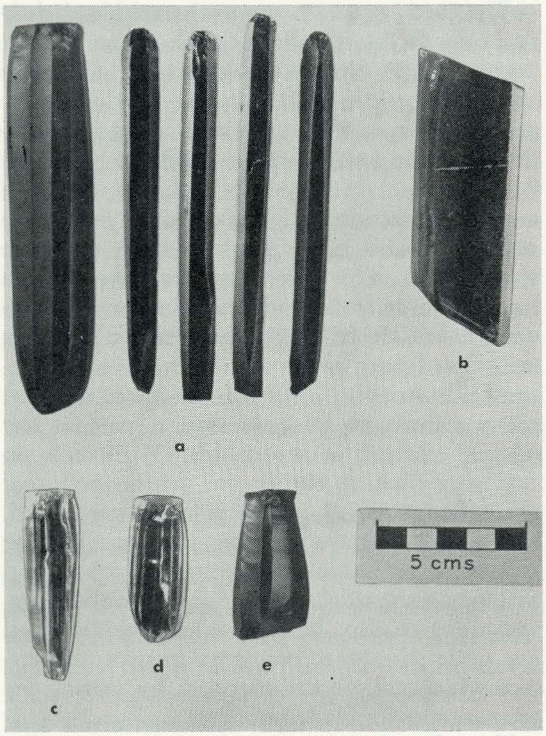


FIG. 6. Cores and blades produced by Crabtree by the pressure method. *a*, obsidian polyhedral core and four prismatic blades (I.S.U.M. Cr 1157; notice the regular nearly parallel sides of both the cores and blades, the small bulbs of force at the upper end of the core, the very subdued nearly lacking undulations on both the core and blades, and the characteristic flake scars at the platform end of both core and blades showing removal of overhang); *b*, rectangular glass core with sloping platform (I.S.U.M. Cr 1161); *c*, elongate conical polyhedral core of glass (I.S.U.M. Cr 1162); *d*, small polyhedral core of glass (I.S.U.M. Cr 1163); *e*, small polyhedral core of obsidian (I.S.U.M. Cr 1166), showing constriction below platform and the overhanging lips which should be removed in order to successfully detach another series of blades.

rial, and I have tried this method both with and without the use of an anvil. I have used as tools both hard and soft hammerstones, wood, antler, horn, bone, shell, and ivory billets, and I have even tried them hafted. Each percussion tool type leaves distinctive flake-scars, and some may be recognized and related to certain core and artifact types, yet none will replicate the prismatic blade or polyhedral core. This method of blade detachment involves the use of an intermediate tool, called a punch, which is struck by a billet or a club.

The punch, or intermediate tool, may be an elongated pebble of varying degrees of hardness, of variable texture, and of different types of stone. The choice of stone depends on the type of material of the core. Hardwood has been used as a punch, with little or no results. It splinters too easily, is much too resilient, and will absorb the force of impact without removing a blade. A punch made of ivory, bone, antler, or metal works much better with this technique. The striking implement is selected from a variety of hammers, billets, and clubs, depending on the type of material being worked and the size of blades to be removed; it must also be compatible with the amount of velocity needed to regulate the curvature, or flatness, and termination of the blades. Velocity can be increased by using a longer handle or a longer billet. The weight of the percussor must correspond to the size of the blade desired.

Indirect percussion technique requires the use of a third hand or a device to replace it. The left hand holds the core, and the blow is struck with the right hand, leaving no means for placing the intermediate tool. Since a second person was not available for these experiments, devices were improvised to hold the core so the left hand could place the punch. Heels or feet may be used to hold the core, but the worker must be apt at holding with the feet, and he must also have the assistance of an anvil to further immobilize the core. I have found that two poles, flattened on the inside at the holding end and loosely tied with lashings to permit insertion of the core, make an excellent holding device. When the core is placed between the flattened surfaces of the butts of the poles and the opposite ends are spread until the desired amount of tension is obtained, the core will be held firmly and securely. This indirect percussion method will produce blades, but they will not have the characteristics of blades removed by pressure (Figs. 3*a* and 7*b*). The impact from the percussor causes excessive undulations and waves on both the core and blade; the dimensions of the blade cannot be controlled with regularity; the bulbs of force are much too large, and the curve of the blades and termination of the ends cannot be controlled. Because of the angle of impact, the resultant core form is not one with parallel sides, but it assumes a conical shape. When this method is used, the blades have better form if the material is flint than if it is obsidian, because the wave mechanics of obsidian are more pronounced than those of flint.

An unconditional requisite of preforming polyhedral cores is to first establish corners (ridges) on the preformed core. Without these ridges there can be no polyhedral shape and no prismatic blades, for they are used to remove and guide the blades, and they are the inception of the "faceted" shape of this core. If the percussion preforming has left these corners (or ridges) uneven, or not straight, then they must be straightened by careful retouch until they will produce a straight blade (Fig. 3*b, d*).

Preforms may have as few as one ridge, or as many as the worker can create. However, with just one ridge, it is unlikely that the finished core would assume the true polyhedral shape. The core is always percussion preformed to be rectangular in shape, with corners which will be established as ridges either by percussion, indirect percussion, or pressure. It is of prime importance that the ridge be absolutely straight and vertical to the proximal and distal ends of the core; any irregularity or deviation will cause the first and all subsequent blades to be malformed, and since this error cannot be overcome, all blades will be distorted. These variations of preforming will be covered under separate preforming methods:

1. core with one ridge (Fig. 4*e*)
2. core with two ridges (Fig. 4*f*)
3. core with three ridges (Fig. 4*g*)
4. core with four ridges (Fig. 4*h*)
5. core with more than four ridges.

Preparation of the Core

1. *Core with One Ridge:* The simplest form of core manufacture for prismatic blades is to establish a single ridge on the core to guide the first blade. A mass of obsidian is selected; this may be either a large cobble or a lump with a natural flat face. Should the cobble be round and without a natural flat surface, it must be modified, and this is done by percussion to divide the cobble in half. Each half of the cobble can then be used to prepare a core for pressing off blades. Half of the cobble is held in the left hand and placed on the thigh of the left leg, with the flat surface of the rock exposed. Strike a blow at right angles to the flat surface, but near the edge, to remove a single large flake the entire length of the cobble. This is to remove the cortex of the cobble and also to establish a corner perpendicular and at right angles to the top of the core.

The next step is to rotate the cobble slightly and remove another flake in the same manner, positioning the blow so that the second flake-scar will intersect the first flake-scar and produce another corner; this establishes a ridge for removal of the first prismatic blade. If this large flake is removed properly, it should leave an angular projection (ridge) the full length of the cobble. If this ridge is irregular, it must be straightened. This is done by percussion, using a small hammerstone and removing small transverse flakes, either unificially or bifacially, along the entire length of the vertical line of the ridge, until it is straight. This will, at the same time, remove the cortex, or at least a part of the original surface, of the cobble. If there is an overhang (lip), or bulbar scar, left at the top of the core (or ridge) at the point of percussion, it must be removed during the straightening process. This is done by turning the cobble and striking on the ridge, at right angles to the ridge, just under the lip. This blow must be delivered just under the lip to prevent damaging the surface which will be the platform for seating the pressure tool for blade removal.

Now the platform must be prepared on the flat top of this ridge. This is done by roughening the surface (scratching or grinding) with a piece of siliceous stone, quartz sand, or material at least harder than obsidian. This is necessary to prevent the tip of the crutch from slipping.

The prepared half of the cobble is then secured in a suitable clamp with the ridge facing away from the clamp. The first pressure blade is then removed by the use of the chest crutch. The first blade will bear the scars of the ridge-preparing flakes and will resemble a unifacially flaked tool. But it will differ in that these scars will show that force was applied from the median line out to the edge, whereas a unifacially worked tool is just the reverse.

A variant of this single-ridge method is to use a very large single tabular flake struck from a mass of obsidian by percussion. This is done by using a large hammerstone and striking from a cobble, first, one large flake to get a flat surface and, next, striking one blow directly behind to remove a thick flake with a flat surface. The first flake is discarded, since it lacks conformity. The striking distance of blows in relation to the edge will determine the thickness of the large flake, which should be about 2 in. thick. For the platform, the top of the flake should be made flat by removing a large burin spall by percussion.

Then the edge of the flake is bifacially flaked to form a ridge which will be at right angles and vertical to the top, or the platform surface.

Removal of the first blade will establish two ridges to guide the next two blades, and so on. As additional blades are removed, the core will assume the shape of a half-cylinder; when it is exhausted, it will not be polyhedral. The unworked portion, or back, of this core will retain the character of the original surface, and only the worked portion will show the longitudinal scars left by the removal of blades. When blades are removed around the entire periphery, there is no indication of what the original core type was, unless an assemblage of the blades can be associated with the core and the core can be reconstructed.

2. *Cores with Two Ridges:* Prismatic blades may also be removed from a core having two ridges. This type is made in much the same manner as the core previously described as a variant of the core with one ridge. However, after the burin spall has been removed to create a flat surface at the top for the platform, another large burin-type flake is removed at right angles and vertical to the first to establish two corners to guide the first two blades. Looking from the proximal end downward, the edge of the core should appear to be rectangular. If the ridges are irregular, they may need a slight amount of modification not only to make them perfectly straight, but also at right angles to the proximal end of the core. This core will normally still retain the original surface on one side.

A variant of the two-ridge preform core is to make an object resembling the broken end of a large bifacial artifact (Fig. 3*c*). This type of preform core resembles a tongue, with the lateral edges serving as the ridges to guide the initial blades. The proximal end of the core must be flat to provide a platform for the pressure tool. This flat surface is made by striking a percussion blow on one of the lateral ridges near the top. Removing this flake from the top of the core is most difficult because it is hard to prevent it from terminating in a curve on the opposite side. If I prepare the platform after the bifacial ridge flaking is done, I turn the core and strike on one of the lateral edges (ridges) across the top of the core, but I direct the blow to remove a flake at right angles with the long axis of the core. This will terminate the flake on the opposite lateral edge of the top, and thereby it confines the curve to a restricted area. The surface character of a bifacial artifact accidentally broken will show a different break pattern, or lines of force, than this type of core. The lines of force of the broken artifact will not start at the lateral edge, and the break will be at right angles to the long axis. Also, the curve of the broken artifact will extend from one edge to the other, rendering the edge useless to seat a pressure tool. The bifacial core is made and designed on the previously prepared flat surface in order that it may be perfectly flat on the proximal end of the core.

The bifacial core is first shaped by percussion with a soft hammerstone; then, using an antler billet, it is made symmetrical. This is done in much the same manner as in making a large bifacial tool except that the specimen will be left much thicker in section. Preforming includes establishing two ridges to guide the initial blades on the marginal edges. The first blade removed from each ridge of the bifacial core will be triangulate in section, and the dorsal side of the blade will bear the bifacial flake-scars of the first preparation. The ventral side of the blade will be smooth but slightly convex in section, with the curve extending from the point of pressure to the point of termination. The curve will be concave on the ventral side and will resemble an archer's bow (Fig. 3*c*). A core of this type could be mistaken for a broken bifacial artifact if work was stopped at this point and no other blades were removed.

3. *Core with Three Ridges:* Another experimental core is one with three ridges to guide the blades. A piece of obsidian with a natural flat surface and of the right thickness and length must first be selected. With a large hammerstone, two large flakes are removed from either side of the center, at right angles to the top of the core. After removal of these two flakes, the obsidian block should have the appearance of the forepart or prow of a boat (Fig. 4*g*).

Then the block is struck on the top, with the hammerstone, exactly in the center in line with the two previous flake-scars. Now the three sides of the original mass have been removed, and a large triangular piece of obsidian, which is the core, is left. This triangular core requires little modification on the three ridges. The overhang left by the bulbs of percussion must be removed, and, if necessary, the ridges must be straightened. This modification can be done either by very careful application of percussion or by the use of pressure. Should one be working with a cobble or a rounded mass of material, the core would be prepared in a manner similar to the rectangular core, except that it would have three sides.

4. *Core with Four Ridges:* When preforming a core with four ridges, it must be made cube-like. Then as the blades are removed, the core will assume the form of a regular polygon with as many facets as there are blades removed. The abandoned and exhausted cores of Mexico indicate that the rectangular type of core was by far the most common. A core 2 x 2 in. at the proximal end can yield as many as a hundred usable blades, provided the worker encounters no material or manufacturing difficulties. The making of the rectangular core is considerably more complicated than the making of a simple bifacial tool, and it represents a highly specialized industry.

Since the isotropic homogeneous qualities of obsidian make it devoid of cleavage planes, preforming the core becomes a very exacting work. Using a simple hammerstone, the mass of obsidian is reduced into a rectangular shape with a perfectly flat surface to form the proximal end (Fig. 4*h*), and the sides must be parallel, perpendicular, and at right angles to the proximal end. Primary flaking of the core is done with a flat-surfaced hammerstone, for this flatness will diffuse the bulb of percussion. Flakes are then struck off the mass until the core is rectangular.

In order to shape the mass into a rectangular form, before each flake is struck it must be evaluated and considered individually with reference to the final rectangular form. It would serve little purpose and would require far too much description to describe the removing of each individual flake. It is sufficient that one know that the core is formed by percussion and must be rectangular in shape. After the core has been made rectangular, the corners may be removed by striking percussion blows with a hammerstone or, if one is not adept at percussion, this can be accomplished by pressure, with the aid of the chest crutch. After the corners are removed, the core will be octagonal or roughly cylindrical in shape.

After the core has been made rectangular, ridges may be made by intersecting the two longitudinal flake-scars by either unifacial or bifacial retouch. Either pressure or percussion may be used for this work, depending on the size of the core. Also, to flake these ridges, using indirect percussion with punch has proven most successful. If the punch is used, the ridge is straightened and made regular by alternating the flakes from right to left on either side of the proposed ridge, each bulbar flake-scar providing the platform for the next flake. Flaking of this ridge is started at the distal end, and it continues alternately from right to left the entire length of the core. When the flaking process reaches the proximal end, extreme care must be used in flaking or the platform which will seat the tool to remove the blades will be damaged.

A ridge made in this fashion will have a sinuous appearance (Fig. 3*b*). This technique of establishing ridges has been used in my experiments and, I believe, was used by the aborigine. However, I do not mean to imply that all cores were made in this manner. Further study at the actual sites will reveal much information and resolve the technique.

Sawed Cores: Purely for the purpose of studying the consistent behavior of force in relation to isotropic material, I have at times used a rectangular shape of obsidian which has been cut by a diamond saw (Figs. 4*c* and 8*a*). The sawing procedure conserves material, although it does have disadvantages. It causes scoring on both sides of the cut, which weakens the obsidian and leaves the material with the appearance of ground glass. The first blades removed from a sawed surface must be thicker than one would normally expect, and, until all of the sawed surface is removed, one must progress with caution or the blades will break before they are detached from the core. Another disadvantage is the lack of curvature on the surface, which makes it difficult to remove the blades.

PREPARATION OF THE PLATFORM

Platforms: Preparing the top of the core to serve as a platform for the pressure tool is the next step before blades can be removed.

Flaked Platform: Before I had an opportunity to study original cores, I prepared the platform by removing a small flake to seat the pressure tool which was, I later learned from Dr. R. S. MacNeish, much the same as on the early cores of Mexico. He observed (personal communication) that some of the tops of the early cores had a flaked platform surface and some had a natural rough cortex. My first platform experiment was to remove, by pressure, a small flake directly above the ridge. The bulb of pressure left a depression in which I could place the tip of the pressure tool. This prevented the pressure tool from slipping when downward and outward

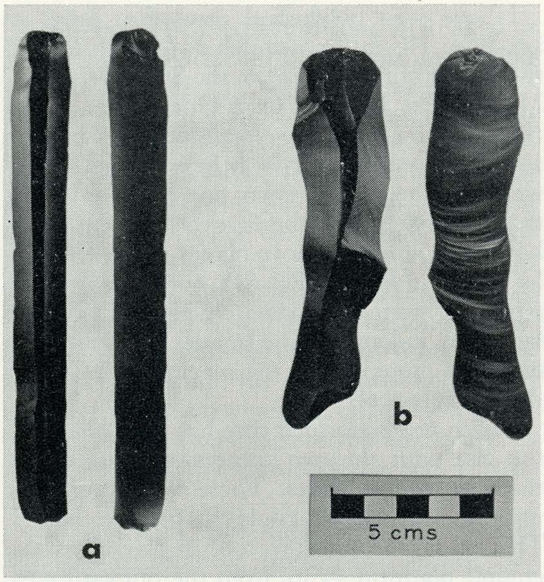


FIG. 7. Comparison of obsidian blades made by pressure and indirect percussion techniques. Both specimens produced by Crabtree. *a*, shows front and back surfaces of an obsidian blade made by pressure (I.S.U.M. Cr 1180); *b*, shows front and back surfaces of an obsidian blade made by indirect percussion (I.S.U.M. Cr 1182; notice the straight nearly parallel edges of *a*, the irregularity of the edges of *b*, and the heavy undulations and the prominent bulb of force on the back surface of *b*, which are much more subdued on *a*).

pressure was applied. But this technique has one disadvantage: After the first series of blades has been removed from around the entire perimeter of the core, the top then has a convexity, and this curve prohibits the seating of the pressure tool; therefore, it is necessary to rejuvenate the core by removing the entire top. This rejuvenation is most difficult since the top of the core must be severed by removing a single flake with one blow and without leaving a rounded edge on the opposite side of the core top. I have never been satisfied with the termination of the rejuvenating flake, but I continue to experiment with this technique. Dr. Robert Heizer showed me some severed cores from Guatemala which appeared to have been broken by the use of heat and cold. He will, perhaps, have more information on this method when he returns from the site in Guatemala. This rejuvenation of the top of the core causes the core to be shortened each time a series of blades is removed from around the periphery of the core.

Scored Platforms: My experiments have shown that grinding or scoring the platform surface prevents the pressure tool from slipping when downward and outward pressure is applied. This allows the worker to continue to remove blades until the complete core has been exhausted. The grinding technique is also useful to overcome the human factor of miscalculations in placing the pressure tool. If the tool is placed too close to the edge and if there is not sufficient material to withstand the force, the platform will sometimes crush before the outward pressure can be exerted. Should this happen, the core must either be abandoned or be ground from the top toward the base until the damaged area has been removed. I have observed that the aborigines also used this method of recovering their cores. A careful examination of the top of the core will reveal if the bulbs of pressure have been eliminated. If there are none, then, very possibly, the top of the core was rejuvenated by the severing or grinding techniques.

BLADES

Blade Removal: Assuming that the obsidian has been properly preformed into a core with ridges, the platform is ground until it has the appearance of frosted glass, and the core is now immobilized in a clamp, ready for blade removal. The pressure crutch has been made, and the specimen is now ready for removal of the first blade.

But before a blade is actually removed, it is important to consider the actual removal of a prismatic blade from the core. A specialized flake (called a blade), long and thin and with two parallel sharp cutting edges, is desired. This type of blade has unlimited uses. Indeed, it added much to the economy of many people prior to the use of metal. There is absolutely no resemblance or comparison between this elongated flake and the conchoidal fracture flake (Figs. 5*b* and 7*a*). The prismatic flake is not round or oval; it is either trapezoidal or triangular in section, and it does not have waves or undulations. The dorsal side is characterized by two or three facets left by scars from previous blade removal; these facets are the result of the ridges created by the worker to guide each blade removal. This is the marked difference between a conchoidal fracture flake and a prismatic blade — the conchoidal fracture flake is made on a flat surface with a hard hammer, and there is no ridge, or mass, to control, guide, and prevent the spreading of the flake.

Prismatic blades will be no straighter than the ridge left on one face of the core; therefore, care should be given to the retouch of this ridge during straightening to see that it is left without a sinuous shape. The thickness of the flake is governed by the seating of the pressure tool on the platform. If it is set close to the edge at the top of the core, a thin blade will result. If it is set far back, the blade will be thicker. The thickness of the blade is mainly controlled by the preparation of the longitudinal surface of the core. Should a thick blade be desired, the ridges from the top to the base must be isolated by blades removed from each side of the proposed thick blade. For repeated thick blades, the use of thin tabular cores is required. The seating of the pressure tool farther back from the edge of the top will also assist in taking off a thicker blade, but this usually results in the removal of the distal end of the core. The width of the blade is controlled, too, by the steepness of the angle of the preestablished ridge. The more obtuse the angle, the narrower the blade. Removing these prismatic blades from the core by means of pressure involves problems that are not present when blades are removed by percussion. Each flake, or blade, is a part of a cone. In the case of the pristmatic blades, the first blade is one quarter of the complete cone. The balance of the blades are still portions of cones, but at this time I cannot be certain what portion of the cone is detached with the balance.

The technique for removal of a cone part is to start at the platform and then with downward and outward pressure to thrust the cone along the outward surface to the distal end. The downward and outward pressures change the angle of this cone. If only downward pressure is applied, the angle of the cone will veer inward into the body of the core, producing a true quarter of a cone, but this will terminate in a step fracture before the blade has been detached at the distal end. If both downward and outward pressure are applied simultaneously, then a quarter of a cone is produced. The angle of the cone will change as the outward pressure is increased; it becomes parallel with the face of the core, thereby permitting the removal of a long narrow blade.

Removal of blades by percussion presents a different problem; the worker must strike with the angle, conforming to the angle of the cone, or he can alter the angle of the platform to conform with the angle of the blow (Figs. 1*h* and 6*b*).

I have seen polyhedral cores that range in size from 1½ in. to as much as 9 in. in length; the largest of these are from the State of Colima, Mexico (Fig. 1*a*), and from Guatemala. These represent the size of the exhausted cores, but the size of the preformed core before the first blades were detached is unknown; and one wonders at the immense size of the first series of blades. I have been able to remove blades ⅞ in. in width by 7½ in. in length (Fig. 6*a*), but I prefer to use a block of stone approximately 3½ in. at the top by 5½ in. in length. The smaller the core, however, the more critical the placing of the tip of the pressure tool.

When the preformed core has been placed in the vise with the two corners exposed, one is ready to remove blades. These two corners bear the ridges which will guide the first two blades. The tip of the pressure tool is placed on the ground platform $\frac{1}{16}$ in. from the outward edge of the core; the chest crutch is then positioned on the chest with the top of the "T" portion of the crutch against the lower pectoral muscles of the chest. The chest rests on the crutch, which is centered directly above and in line with the ridge that will guide the blade. The hands grasp the shaft firmly on a spot just below the slightly bent knees. By pressing with the knees against the hands, additional outward pressure may be obtained if the core is too large to detach blades by pressure from the hands alone. When very large blades are being detached from the core, the worker can help detachment by dropping the weight of the body on the crutch and simultaneously bending the knees and striking them against the hands and, at the same time, coordinating the balance of downward and outward pressure to the tip of the crutch.

The platform of the core will usually support the entire weight of the body until outward pressure is applied.

The first flake or blade will be triangulate in section; it will terminate with an expanding distal end and will remove a portion of the distal end of the core. The distal end of the first blade will be more curved than the balance of the blades will be. Slightly more downward pressure is required to remove the first blade than is needed for subsequent blades. This is to assure its complete removal, to give the core a better form for removal of the balance of the blades, and so that subsequent blades will have straighter ridges to follow and will not be malformed. If

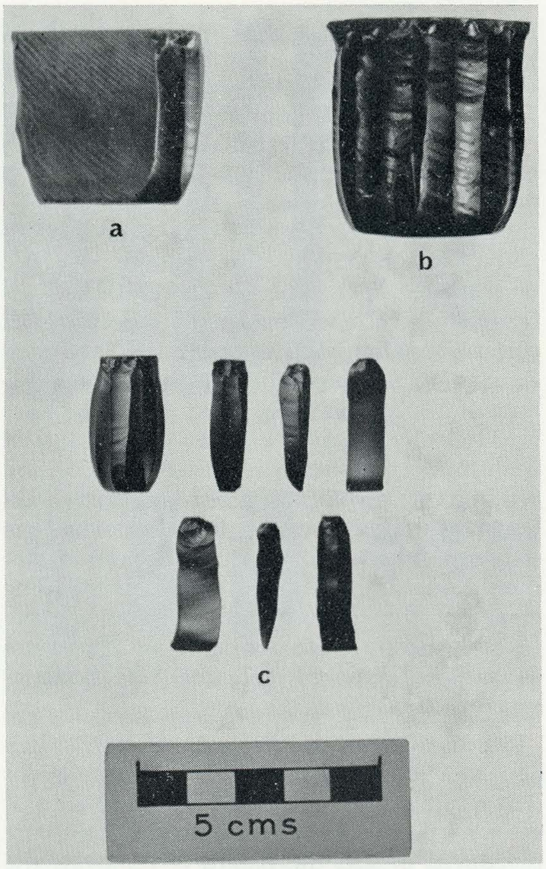


FIG. 8. Cores made by Crabtree using pressure and the Arctic technique. *a*, small obsidian core showing the use of a sawed core preform (I.S.U.M. Cr 1148); *b*, small obsidian polyhedral core (I.S.U.M. Cr 1095) shows overhanging lips at edge of platform which are usually removed before detaching another series of blades; *c*, obsidian microcore and six microblades (I.S.U.M. Cr. 1147).

the core is rectangular, all four corners are removed in the same manner. After blades have been removed from the two corners, the flake-scars left by their removal make four ridges to guide the next blades. In these experiments, I have used two methods to detach the next blades:

1. If the blades are to be narrow, I place the tip of the presure tool directly above and in line with the ridge, and I repeat this placement on all four ridges. Like the first detached blade, these blades will also be triangulate in section.

2. The second method involves trimming off the overhang left on the edge of the core by the bulb of pressure. If the platform is not prepared in this manner, it will crush when pressure is applied and will thus ruin the core. This preparation is required in order to free the platform and to allow positioning the tip of the pressure tool on the edge of the core between the two ridges left by removal of the first blade.

Removing a blade by this method will result in a blade with the two ridges left after removal of the first blade, and it will not be triangular in section but rather will be trapezoidal. This type of prismatic blade is the more common (Figs. 6*a* and 7*a*), or the standard, type found in the Valley of Mexico. Its dorsal side is flat with both edges terminating in an acute angle, to a very sharp edge. These two blade types are very familiar to the archaeologist, but there are aberrations having more than two ridges and other abortive forms which usually indicate poor judgment or miscalculation by the worker.

Blade types are governed by the manner in which the pressure tool is placed on the edge of the core. The triangular blade is made by directly following one ridge, and the trapezoidal type is made by positioning the tip of the pressure tool in line with, but between, two ridges.

The blades can now be removed in the same manner as the first, but before each is pressed off, the platforms must be prepared and freed. When all the corners of the preformed core have been eliminated by the removal of blades, the core will have the appearance of a polygon, or it will be cylindrical in form. When blades have been detached from the exposed surface of the core, then it must be repositioned in the clamp to expose a new surface. It must be repositioned in the vise at the same angle as the previously worked surface, or the blades will not be uniform. When the core has reached a cylindrical shape, all of the platforms over the ridges may be prepared at the same time. This enables the worker to remove blades without stopping to prepare the platform each time. By constant practice, rhythms and muscular motor habits, which aid in removing uniform blades (Fig. 6*a*), are developed. Practice, good muscle control, and a knowledge of the amount of force required for removing blades of various sizes result in duplication of uniform blades.

Experience enables the worker to achieve control of the termination of the blades, and he can even learn to stop the blade midway along the face of the core either in a feather edge or by a hinge or step fracture (Figs. 3*c* and 9*e*). The feathered edge is accomplished by increasing the amount of outward pressure and simultaneously

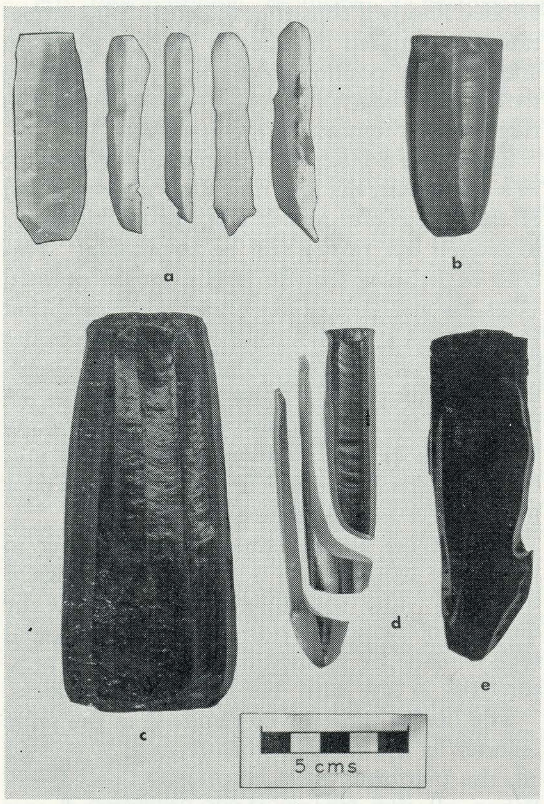


FIG. 9. Polyhedral cores and blades made by Crabtree by pressure. *a*, polyhedral core and four blades of chalcedony from Battle Mountain, Nevada (I.S.U.M. Cr 1139); *b*, polyhedral core of flint from Grand Pressigny, France (I.S.U.M. Cr 1164); *c*, large obsidian polyhedral core showing rippling on flake scars (undulations, compression rings?) owing to the presence of inclusions within the obsidian (I.S.U.M. Cr 1088); *d*, obsidian polyhedral core and two blades showing repeated removal of the distal end of the core with the end of the core adhering to the blade (I.S.U.M. Cr 1140); *e*, obsidian polyhedral core (I.S.U.M. Cr 1170) showing a good hinge fracture (curving break).

reducing the amount of downward pressure. The step fracture is made by dissipating both the downward and outward pressures and, at times, this will leave the blade intact but still attached to the core. Rounding of the distal end of the blade is known as a hinge fracture (Fig. 9*e*). Hinging is accomplished by insufficient downward pressure and excess outward pressure.

In prismatic blade making, it is not desirable, of course, to hinge or step the blades, but this technique can be useful if a blade breaks before terminating at the distal end. When this happens, the worker can sometimes recover the core by applying pressure at the distal end, thus removing a blade up to and intersecting with the step or hinge fracture. Learning to control step and hinge fractures can also be useful in the channel flaking of Folsom and Clovis points.

As the core becomes smaller, the curvature of the blades increases. This is because the bulbar portion of the blade is slightly thicker than the balance of the blade, and the core must be trimmed at the top to compensate for the bulb of pressure. Each time the top of the core is trimmed, it becomes smaller, until no platform surface remains. At this stage, the exhausted core, being a pointed ellipsoid, has the appearance of a submarine (Fig. 1*a, c, d*). Some cores are originally designed wider at the top, and, as each series of blades is removed (Figs. 6*c* and 9*b*), the core becomes progressively shorter until it is abandoned; however, it still retains some platform surface. This type of exhausted core has the appearance of a pointed paraboloid. The angles of the platform on a paraboloid core become slightly more obtuse as the blades are successively removed and the core becomes smaller.

Miscalculations and Recovery of Cores: It is also well to consider here the miscalculations that result in the removal of the distal ends of the cores during blade detachment. As the core is reduced in size, the hazard of removing the distal end of the core along with the blades increases (Fig. 9*d*). As the proximal end of the core becomes smaller, the platform areas become isolated; when this happens, it is very easy to position the tip of the pressure tool too far from the edge of the core, causing the blade to be thicker than normal. The thicker blade allows the force to spread, and this will sever the core because of the reduced diameter of the core. To overcome this, the tip of the pressure tool is placed closer to the slightly abraded edge, and the amount of outward pressure is increased. The removal of the distal end of the core, with the blade, may result, even when the core is not reduced in size, if an excessive amount of downward pressure is applied (Fig. 14).

The angles of the lateral edges of the parallel-sided blade may be changed from obtuse to acute by using a thinner core. A core of thin tabular material can be used to make successive triangular blades. The flatter the surface of the core, the more obtuse the angle of the blade section and the flatter the blade.

The recovery and rejuvenation of cores are most important when there is a shortage of material or when the time factor of preparing a new core is considered. There are many reasons why the worker cannot remove a blade with each attempt. The tip of the pressure tool may become contaminated with small fragments of stone; this allows it to slip and thereby destroys the platform before a blade can be removed. The platform may collapse and be destroyed by placing the tip of the pressure tool too close to the edge, which will not provide sufficient material to withstand the force. If the core is not properly secured in the clamp and if it moves when outward pressure is applied, the pressure tool will slip and damage the edge of the core. When the platform is destroyed, the top of the core may be rejuvenated by removing a single flake across the entire top of the core, the core may be ground down until the damaged portions are eliminated, or, occasionally, a new surface may be found beside the crushed portion and a blade can be removed without too much distortion of the blade and core.

The imperfections left by a step or hinge fracture may sometimes be overcome by using the fracture of the step or hinge as a platform to place the tip of the pressure tool and then by pushing off the balance of the blade; however, any imperfection left on the core will disfigure the next series of blades. There is another method of recovering a core which has been spoiled by a blade hinge or step fracture during detachment. This may be accomplished by creating a platform on the distal end of the core directly in line with the blade broken from the top of the core, though this is very difficult. When such a platform can be made, then the broken blade is pressed from the distal end of the core to intersect the hinge or step fracture and, if successful, the worker recovers the core and can continue in the original manner of blade removal.

To date, I have not experimented too much with blades exceeding 12 in. in length; however, I have been successful in removing some of this size. Efforts to produce blades of this size have been curtailed because of a lack of massive material and because of the absence of a co-worker. I have, however, made many attempts to remove large prismatic blades by direct freehand percussion. I have used obsidian, but it does not have the resistance to end-shock found in flintlike materials, and it is too brittle to withstand the impact. It is possible to remove blades from a large core, but breakage is excessive, and it is unusual to remove a complete unbroken blade. I have, nevertheless, been successful when using a combination of pressure and percussion. One person applied the downward and outward pressure while the second person struck a projection on the shaft of the pressure crutch (Fig. 2*b*). I look forward to carrying out further experiments with this method when quantities of massive material are available.

Prismatic Blades Using a Short Hand-Held Staff: I have recently successfully experimented with making polyhedral cores and blades with the aid of a short hand-held staff. Not long ago, I visited Dr. Charles Borden at the University of British Columbia and reviewed much of his Pacific Northwest material. Among his collections were many microcores and blades. They were shorter in relation to their diameter than the cores of Mexico, but the techniques appeared to be somewhat parallel. I noticed that the technique of platform preparation and the technique of blade removal indicated that different techniques were used and that these were related to different materials. During a short demonstration of stoneworking to the students, an attempt was made to replicate this style of blade removal. Since I was not prepared for this demonstration and had not brought along my tool kit or chest crutch, I improvised by using just an antler tine and a hurriedly made vise to remove the blades. The antler tine was approximately 12 in. long and was pointed at the distal end. I improvised with leather thongs and a clamp made of two tent stakes tied at one end. The core was inserted near the lashed portion; then the clamp was spread at the opposite end, and a small cobble was inserted between these stakes and was pushed forward toward the core until it was tight in the vise and secure. Then I knelt on the stakes and seated the tip of the antler tool on the extreme edge of the core platform between two ridges, and with downward and outward pressure I removed a series of bladelets.

When I returned home, I made some experiments to employ this method in making prismatic blades (Fig. 8). Using a hammer handle, I inserted a piece of bone at the tip to make a small pressure tool for removing these prismatic blades. The core was immobilized in the same manner I have described previously, and the same working techniques were employed. I now find that blades up to 4 in. in length may be made by this method and with the use of this tool. Blades larger than 4 in. must still be removed by the use of the chest crutch.

This tool can be used either as a short staff for pressure removal of prismatic blades and microblades, or it can be used as a long-handled pressure tool. When it is used as a staff, it is grasped at the top with the right hand, near the tip with the left hand, and the tip is placed on the prepared platform. The right hand supplies the downward force while the left exerts the outward pressure and thereby removes the blade. This short staff can be used for removing narrow blades but not for longer and wider blades for, the wider the blade, the greater the amount of pressure that is required.

Relating Force to Stone Tool Manufacture: My efforts to replicate the Mexican cores by pressure have revealed some interesting facts regarding forces. When one is cleaving, breaking, preforming, or flaking lithic materials, he becomes aware of the differences in the amount of force necessary to cleave or remove flakes with the same surface area.

An example of the amount of force necessary is provided in the cutting of glass by the scoring method. A piece of plate glass ¾ in. thick and 8 in. long, evenly secured to a solid workbench and with an inch protruding from the edge, will support several thousand pounds, if it is unscored. After it has been scored by a glass-cutter wheel, it may be broken quite easily with but a fraction of the pressure necessary in the unscored state. The area of glass broken can be compared to the area of obsidian removed from a core when detaching a blade by pressure. I have removed blades 1 in. wide and 8 in. long by the use of the pressure crutch alone, and yet my total weight is only 165 pounds, which makes it impossible for me to exceed this much downward pressure. The blade can be parted from the core by exerting outward pressure, causing the blade to separate from the proximal end of the core; this indicates that the removal of the blade begins at the top of the core and continues to the distal end. This is true of pressure flaking, whether the worker is making cores or artifacts. It also occurs when one is fracturing by percussion, for the percussion tool is describing an arc rather than descending in a straight line and is thus combining both downward and outward forces. This causes the flakes to be pulled from the artifact in much the same manner as blades are removed by pressure from a core. This technique, however, is only applicable to certain types of percussion methods. These methods will be described in greater detail later, in another paper.

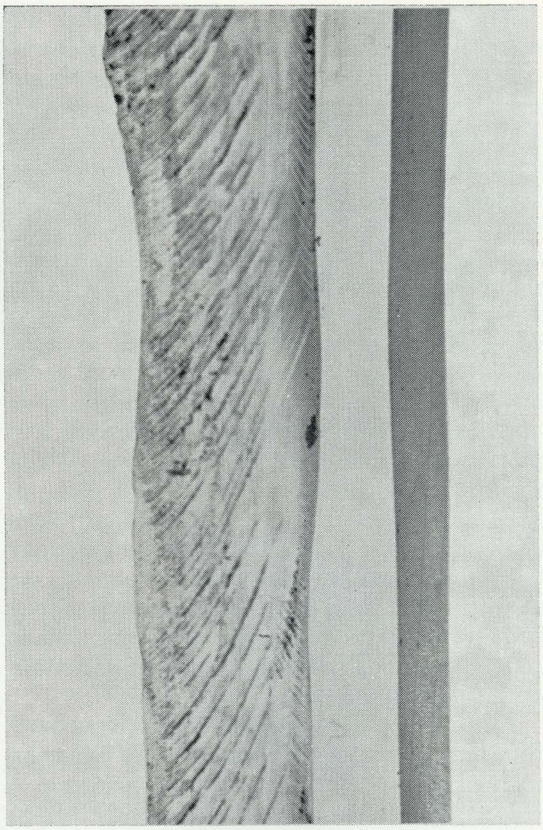


FIG. 10. Portion of the back surface of a large prismatic blade of glass (I.S.U.M. Cr 1141) produced by Crabtree, by pressure, showing the characteristic striations or fissures. Note the regularity of spacing of the fissures and the direction they point, indicating the direction from which force was applied to remove the blade. The platform or proximal end of the blade is beyond the upper margin of the picture.

Close inspection of both blades and cores has revealed a series of evenly spaced corresponding markings on both the blades and the cores that I have been unable, as yet, to analyze or explain. The markings fit and harmonize with both the blade scar and the ventral surface of the blade. These minute striations, or fissures, are peculiar grooves, or channels, characteristic of isotropic materials but more pronounced in the vitreous obsidian and glass-like materials. These are distinctive markings and are extremely useful for both the typologist and the student of technology; they are a key to positive identification of the sequence of flake and blade removal for they point accurately to the direction at which force was applied (Fig. 10).

When examining, either by eye or with the aid of a magnifying glass, a blade detached by pressure, one will observe that these fissures are at a 45° angle to the lateral edges; they point in a gentle curve toward the direction of applied pressure, and, occasionally, the longest fissure will be almost parallel with the lateral edge.

The spacing of these striations, or fissures, is remarkably regular, particularly on blades with parallel sides which have been removed by pressure. Blades removed by pressure have the striations on the marginal edges, while a blade or flake removed by percussion has a fissure radiating from the point of impact (or the bulb of percussion) to the distal end of the flake. The fissures are more prominent on the crests of the undulations, which also characterize the percussion struck flake (Figs. 5*b* and 7*b*).

The spacing of these fissures can be from almost microscopic to more than an inch apart, but, once the spacing pattern is set up, the entire group will be consistent. This spacing appears to be governed by the size of the flake — the larger the flake, the wider the space between the fissures. For example: Recently, through the courtesy of Dr. Junius Bird, I received a large block of obsidian from Iceland (166 lb.). This block of obsidian had one broken face, and on this face was a series of these fissures at least one inch apart. The break that caused these fissures appeared to be due to natural causes (such as settling or some diastrophism of the formation in which the obsidian was deposited); the magnitude of these fissures furnished me an opportunity to closely examine their structure. I noted that these fissures have a peculiar form in section. They appear to resemble steps with a very wide tread and a comparatively short riser, with each step between the riser and the tread being rounded. There is also the phenomenon of relatively microscopic strips of obsidian remaining between the tread and the riser, and, at times, they were still attached to the riser, reminiscent of the crest of a wave. Sometimes, particularly when percussion is used, the strip of obsidian is free, or nearly so, and it may be lifted off with a pointed instrument. These strips seem to have a parallelism with the eraillure flakes found on the bulb of force, for they, too, are not firmly attached to either the core or the bulb.

When this phenomenon is studied and understood, it will, no doubt, provide a means of determining the difference between percussion and pressure flaking; however, a sufficient population of flakes should be studied and evaluated before any final conclusions are reached. The patterns of these markings can be related to various toolmaking traditions and should also be useful for definitive technological purposes. At the present time, however, these peculiarities are not fully understood, and there needs to be further investigation of materials which, though solids, have the properties of a heavy liquid.

Obsidian appears to be slightly less viscous than the various crypto-crystalline materials, and, therefore, it is much better for the study of this most interesting behavior of material. The frictional planes of molecular movement and wave motion create ripples and undulations on the surface of the stone, and a study of this aspect of certain materials would indeed add to our knowledge of the mechanics of stone flaking. Some study has been done on this behavior of materials (for example, George McCurdy's paper on the blades of Mexico [1900], which was sent to me by Dr. Jacques Tixier of the Natural History Museum in Paris).

Since McCurdy's (1900) paper and comments may not be readily available, it may be of interest to quote some of his reasons which have merit and which do offer an explanation of the striations on the margins of the blades as well as of the blade scars on the core. McCurdy compares the molecular movement of obsidian to that of a moving glacier. This movement parallels the results of the experiments in flaking obsidian, and thus further proof is offered for the elasticity of material which is a solid, but which has the characteristics of a heavy liquid. McCurdy's remarks concerning these experiments follow (McCurdy 1900: 412):

> The phenomenon of these delicate markings is due to what seem to be 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.
>
> If that be so, they would bear a striking analogy to the marginal crevasses of a glacier however inappropriate may seem the comparison of objects in the sizes of which there is such great disparity. The resistance at the sides of a glacier and the more rapid flow at the center together make crevasses pointing obliquely upstream at angles of about 45 degrees, the direction of the pull, or the greatest tension, tending to produce the fractures is oblique, toward the center, downstream. Hopkins has shown that this pull is strongest theoretically when it makes an angle of 45 degrees with the sides of the glacier, and therefore the crevasses are at 45 degrees with the sides upstream.

> The force in the glacier is gravitation, that in the obsidian flake is *percussion*. By the *percussion* the particles of the mass of the flake would be set in motion. The movement in line with the direction of the applied force, that is to say, along the axis of the flake, would be most rapid. The sides tending to lag behind would produce a tension to be relieved only by fractures at right angles to the direction of that tension. Here again the direction of the tension is oblique toward the center, "downstream," and is strongest when it makes an angle of 45 degrees with the sides of the flake, which it does apparently near the margin, for there the transverse fractures are most numerous, as might be expected — make angles of 45 degrees with the edges and point obliquely "up-stream," to use the glacial terminology.

As shown by the experiments, the word "percussion" used there should have been "pressure."

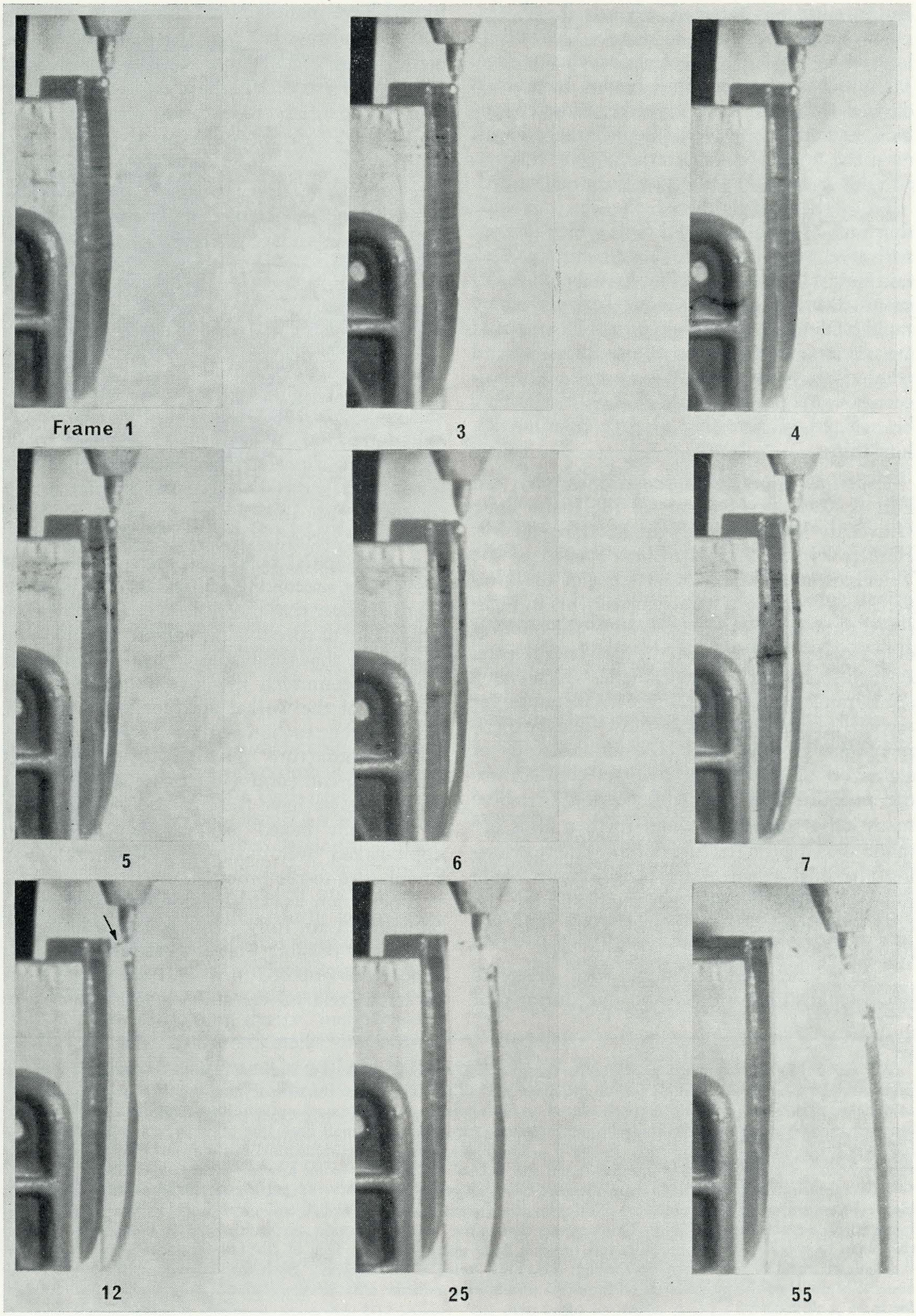
Cutting Quality of Blades: The cutting qualities of the obsidian prismatic blades should be noted, for, to my knowledge, there is no ground or honed material or any metal tool sharper than the obsidian or glass blade replicas of prismatic blades. If the blades are removed properly from the core and are recovered without the edge striking another blade or a hard object, they will have a sharpness that is unexcelled. This sharp edge is the result of the blade leaving the core so quickly that the material is cleaved to the last particle of matter, and the infinitesimal edge converges to zero. Such an edge produces a delicate and exacting cutting implement. However, such an edge must receive discriminate use and care, or it will not sustain its sharp cutting quality.

The sharpness of the cutting edge of these blades was put to the test and made manifest at Grasshopper, Arizona, in July, 1966, when Mr. Gene Seeley used one of my freshly struck prismatic blades to skin a bear. The blade was used for the initial cut of the bear; both hair and hide parted with a minimum amount of pressure, and there was little or no sign of wear on the blade edge. At a later date, Dr. William Longacre, of the University of Arizona, expects to publish a detailed account of the bear-skinning, with emphasis on the function and wear pattern of the stone tools.

My personal experience with the sharpness of an obsidian flake has resulted in much bloodshed while conducting these experiments, for I have received many cuts when working this material. Fortunately, these unplanned incisions heal rapidly. The obsidian is so sharp that it actually severs the cells without bruising; consequently, they unite rapidly and leave no scar. This is not true when one is cut by materials that are less vitreous. Another testimony to the sharpness of obsidian blades is the use of glass knives in the medical profession today. An interesting comparison is that of the Tepexpan man dismembering an elephant with his prismatic blade and the modern scientist slicing an amoeba with a modern glass knife. Apparently the aboriginal tool had considerably more refinement than that of modern man, for I doubt if the modern glass knife could do the job on an elephant.

Glass plate has proven to be the most satisfactory material for making the blades for a microtome. The glass plate is scored and broken in such a manner that the broken edge may be used to section cells, tissue, etc. Several breaks are usually necessary before 1/8 in. of good

FIG. 11. High-speed series photographed at 5,000 frames per second showing the detachment of an obsidian prismatic blade by pressure. Also shows the movement of the eraillure flake and the crutch tip. Frame 1 — The core held in the clamp with the crutch tip properly placed and downward pressure being exerted. Frame 3 — Note the light streak of separation extending about a third of the way down the face of the core as the blade begins to detach with application of outward pressure. Frame 4 — The streak of separation now extends about two-thirds of the way down the face of the core as more outward pressure is applied. Frame 5 — The proximal and middle portions of the blade have been freed from the core. The terminal portion of the blade has probably been freed; notice the slight shadow cast by the blade on the face of the distal end of the core and also that the crutch tip is still in contact with the blade. Frame 6 — Note that the blade is not contacting the crutch tip and that the middle portions of the blade appear to be slightly bowed outward suggesting compression of the blade. Frame 7 — The blade has definitely been freed from the distal end of the core and the eraillure flake has appeared as the tiny dark triangular mass in contact with the tip of the crutch. Frame 12 — The blade has been projected further away from the core and the crutch while the eraillure flake is still adhering to the crutch tip which has moved slightly outward and downward from the core platform. Frames 25 and 55 — Notice the position of the blade, the crutch tip, and the eraillure flake relative to each other and to the core platform. Frames 12, 25, and 55 show that the distal end of the blade travels slightly farther and faster than the proximal end. The movement of the blade relative to the movement of the crutch tip and the eraillure flake suggest that, as the blade is torn away from the core, it recovers from compression and projects itself away from the crutch tip and the core. Note the path of travel of the crutch tip which, along with the removal of the intact blade with a good termination, indicates that the proper balance of downward and outward forces has been achieved.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cutting surface is obtained, whereas the aboriginal workmen were able to remove blades 8 in. long with a total of 16 in. of perfect cutting edge. Many types of microtome blades have been devised from diamond, sapphire, tungsten carbide, and steel; however, when sharpened with even the finest abrasives, striations are present, and this causes the thin sections to be malformed.

From these experiments one can conclude that men of prehistory had tools which, if used with care, were superior to modern cutlery. Certain surgical needs might be better served if surgeons reverted to using stone scalpels where rapid healing is necessary on types of tissues that are viscid and that resist clean incisions, and where little or no scarring is wanted. The surgeon who pioneers the use of such blades may be accused of reverting to cave man tactics, however.

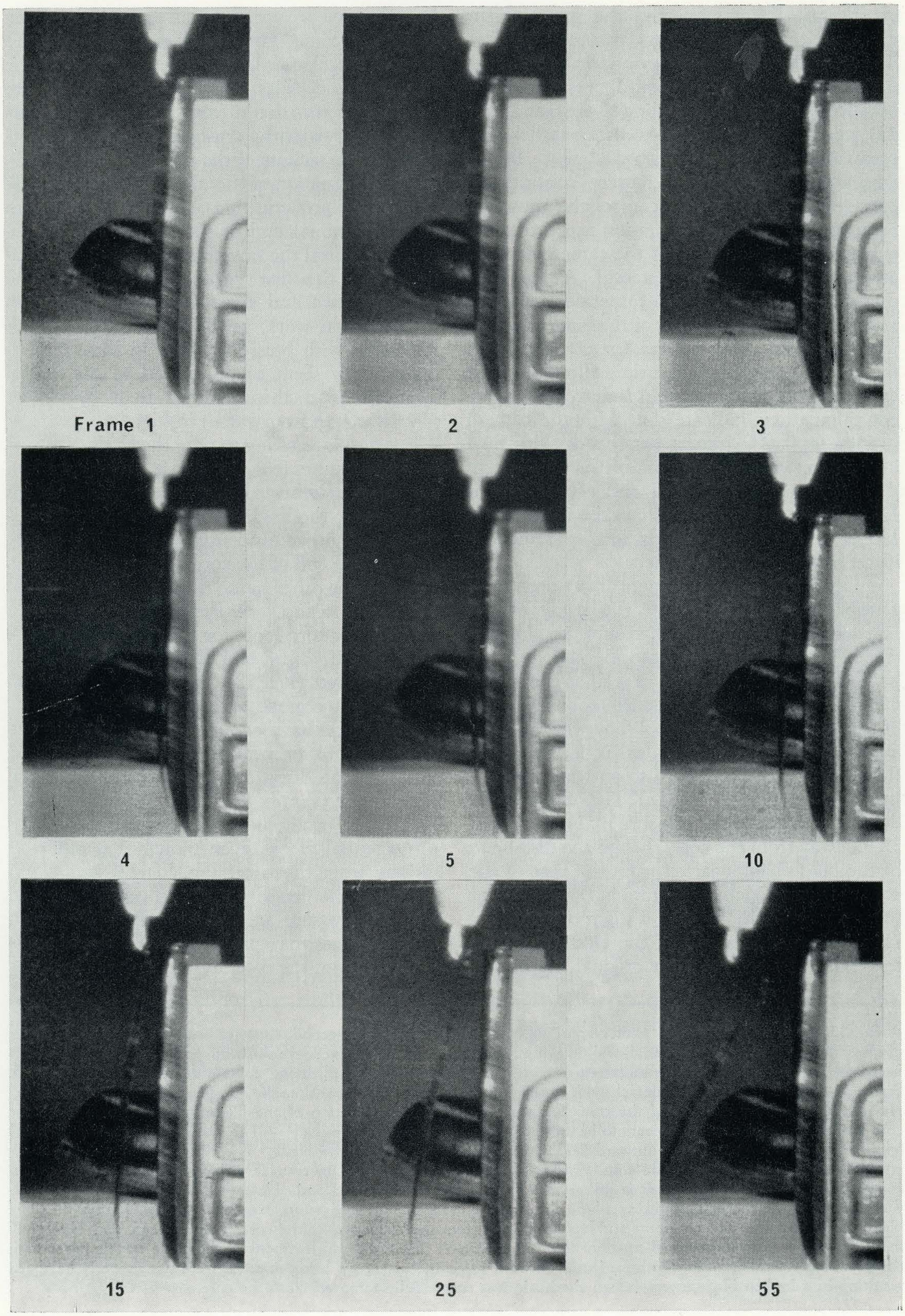
Experiments in High-Speed Photography: Dr. Earl H. Swanson, Director of the Idaho State University Museum, with the assistance of Mr. Herbert Everett and Mr. Elmo Sackett of the Television and Radio Department of the University, is conducting some experiments in high-speed photography of the process of the removal of prismatic blades from the polyhedral core. A high-speed Red Lakes camera, which has a speed range of from 5,000 to 44,000 frames per second, is being used in this study. These experiments are proving invaluable for the study of stoneworking and the behavior of obsidian under pressure, and they will, no doubt, resolve many other questions when further films are made showing the fracture of flint. Prior to viewing the high-speed films of prismatic blade removal, I had thought that the blades left the core at a much slower rate of speed than the film indicated (Figs. 11, 12, 13, and 14).

I have been experimenting with prismatic blade removal for many years, and, during that time, I have manufactured thousands of blades and have always believed that I could feel the blades bend as they tore loose from the core; moreover, I was certain that I could control their behavior. During the pressure removal of the blade, the platform of the blade is first freed from the core by the downward and outward pressure, and it adheres to, or becomes a part of, the proximal end of the blade; then the downward pressure releases the blade the vertical length of the core and terminates it at the distal end. The worker's control, therefore, is apparently a subconscious reaction comparable to the blinking of the eye.

When I am in good form and am familiar with the material, I am able to stop the blades at will and, occasionally, even to leave them still adhering to the core. Yet, the many tests made with the high-speed camera show that the blade is removed in the short interval of three to five frames — with the camera operating at 5,000 frames per second or about 1/1,250th of a second. The initial break has been calculated at 1/19,000 of a second. It is puzzling but enlightening to discover that the blade is removed at such a high rate of speed. This paradox would seem to indicate that the blade removal is controlled by preprogramming the involuntary muscular behavior of the worker and not by consciously directing the reaction of the muscles during the blade manufacture. There is little doubt that the worker can control the bending of flakes or blades, for we have the surface evidence proof on bifacially flaked artifacts that have been ripple-flaked over a curved surface from one lateral edge to the other.

When I am working in front of a high-speed camera and am fully aware of the time limitations, it is possible that I accelerate the blade removal, as opposed to when I am working under more relaxed conditions. It is difficult to

FIG. 12. Series of high-speed photographs taken at 5,000 frames per second showing removal of an intact obsidian prismatic blade and good termination of the distal end of the blade from the core. Frame 1 — The core is positioned in the clamp with the crutch tip properly placed on the platform and downward pressure being applied. Frame 2 — As outward pressure is applied the blade begins to detach; note the very small dark line of separation extending about half way down the face of the core. Frame 3 — The blade shows further detachment as outward pressure continues; the dark line of separation now extends down the face of the core to a point just below the sole of the shoe. Frame 4 — The detachment of the blade from the core has been completed; note the perfect feathered termination of the blade. Frames 5, 10, 15, 25, and 55 — Notice in these frames that the distal end of the blade travels farther and faster than does the proximal end. This suggests that as the terminal portion of the blade tears away from the core the blade recovers from compression and projects itself away from the face of the core and the crutch tip. Note the path of travel of the crutch tip through the entire series of photographs. Both the movement of the crutch tip and the removal of the intact blade with perfect termination indicate a harmonious balance of downward and outward forces.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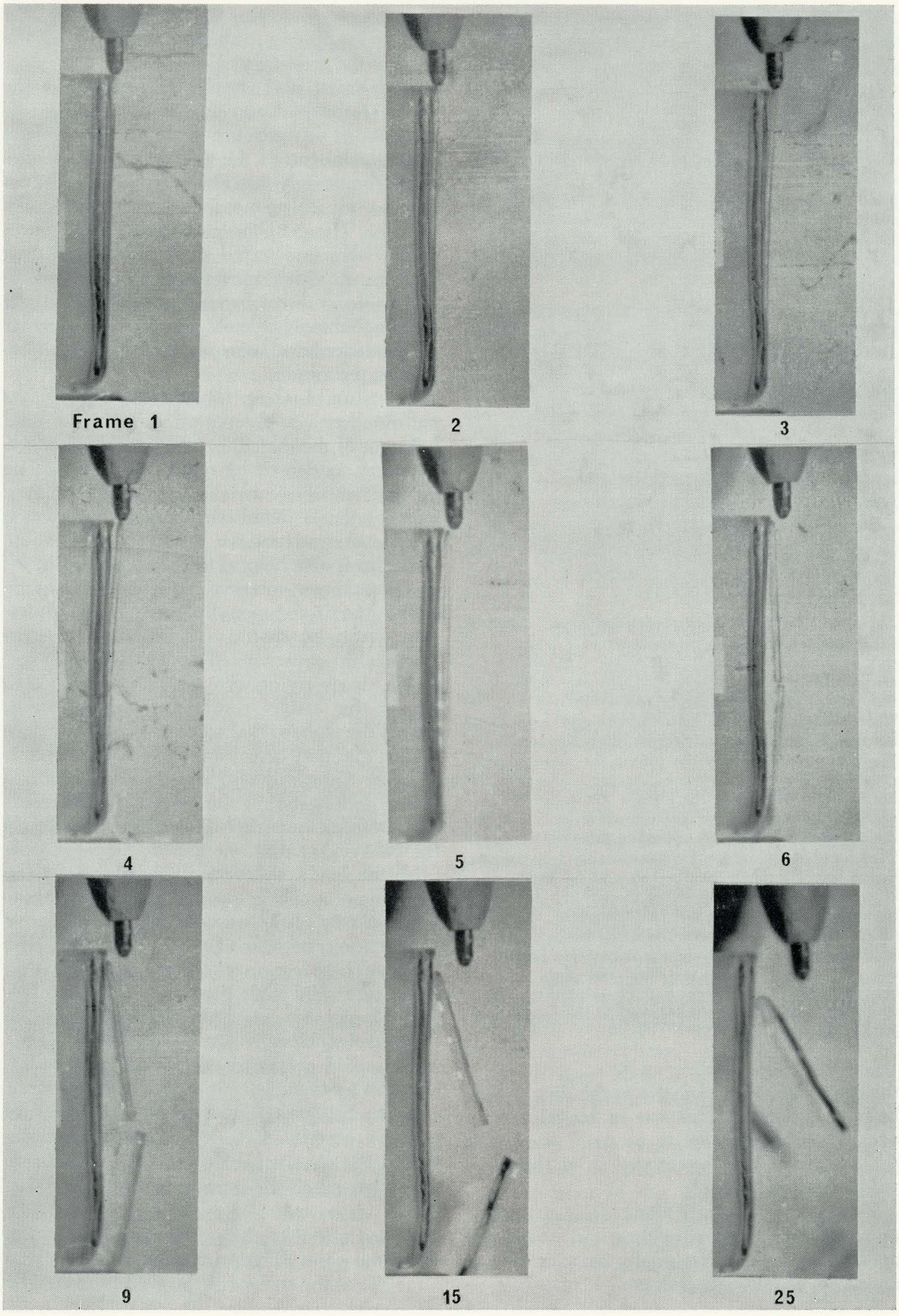
synchronize the camera and the speed of the worker; therefore, the work must be hurried. This necessary synchronization makes it most difficult to apply the outward pressure slowly enough to observe the bending of the blade (Fig. 13), and I have a tendency to thrust rather than press outward and downward slowly. Proper and normal blade removal requires considerable concentration in order to control the muscular behavior, and this concentration is a little difficult under the hot lights of the camera and the attempt to beat the time interval. At this time there is need for continued camera experiments to better correlate the work of the blade removal with the speed of the camera, for as the speed of the camera is increased, the time allotted for the experiment of blade removal is decreased. Present calculations indicate that with the camera running at 5,000 frames per second, the time interval between the parting of the blade from the proximal to the distal end of the core is 1/1,250 of a second. This allows the worker only 1/5 of a second, or slightly less, to remove a blade before the film is gone.

To date, the film experiments have been most rewarding for they permit the study of the behavior of the material when subjected to pressure. It is interesting to note the action of the blade as it leaves the core, as well as the movement of the tip of the pressure tool. The path of the tip of the pressure tool moves at the same angle as the angle of the ideal cone, indicating that the ratio of downward to outward forces is harmonious (Figs. 11 and 12). The outward and downward path of the pressure tip is only about ⅜ in. away from the core, though the distal end of the blade has departed from the base of the core at least an inch away from it. Blades appear to compress in the form of a slight outward arc (Fig. 11); then, because of the elasticity of the material, they assume their original shape and, in doing so, project themselves outward away from the core. The distal end of the blade moves faster and leaves the core before the proximal end (Figs. 11, 12, and 13). As the platform is torn loose from the core, fine particles of apparently crushed obsidian are airborne in the vicinity of the pressure tool tip. Yet, upon examination of the platform, there is little evidence of any crushing on either the platform or the proximal end of the blade. Some photographs reveal the tiny eraillure flake in association with the fine particles (Fig. 11). The eraillure flake and the flake-scar are common to percussion work, yet they are ordinarily not associated with pressure work. In these experiments, they seem to be related to the blades removed by a thrust rather than by slower downward and outward pressure.

It is also interesting to note the angle of travel of the pressure tool tip, for it indicates when too much downward pressure is used. When this occurs, the angle of pressure tool travel is closer to the core and usually results in a part of the distal end of the core being removed (Fig. 14). On the other hand, if the angle of this tool is away from the core, the blade is terminated before it has torn loose for the full length of the core, and the distal end of the blade is straight and feathered (Fig. 12). When the downward pressure is too great, and when the ridges guiding the blade have enough mass to contain the blade and to prevent it from spreading and removing the distal end of the core, the blade flexes to the point of breaking. If fracture of the blade does occur, it usually breaks into three almost equal pieces, even though it is removed entirely from the core(Fig. 13). If and when the tip of the pressure tool and downward and outward pressure are not directly in line with the two ridges that guide the blade, the blade is removed from the core, but it breaks as it leaves

FIG. 13. Series of high-speed photographs, taken at 5,000 frames per second, showing removal of prismatic blade of glass, the elasticity of the material, and breaking of the blade owing to excessive outward pressure. Frame 1 — The core is held in the clamp with the crutch tip properly positioned on the platform and downward pressure being applied. Frame 2 — The blade begins to detach with application of outward pressure. Note the fine line of separation extending about half way down the face of the core. Frame 3 — The proximal portion of the blade has been freed from the core while the distal portion appears to be still connected to the core. Frame 4 — The outward force is still being applied; notice the pronounced outward flexing of the proximal end of the blade. The distal portion of the blade appears to be still adhering to the core. Frame 5 — The crutch tip is not in contact with the blade platform, and it is difficult to see whether the blade is still attached to the core at the distal end. Note the dark streak cutting across the blade near the midpoint showing where the blade is breaking outward from excessive flexing. Frame 6 — The blade has broken into two segments and has been freed from the distal end of the core. Frames 9, 15, and 25 — Note in these three frames the path of travel of the crutch tip and that the distal fragment of the blade travels faster than the proximal fragment. The downward and outward forces necessary for blade removal were not properly balanced resulting in a broken blade, even though the blade was successfully removed from the core.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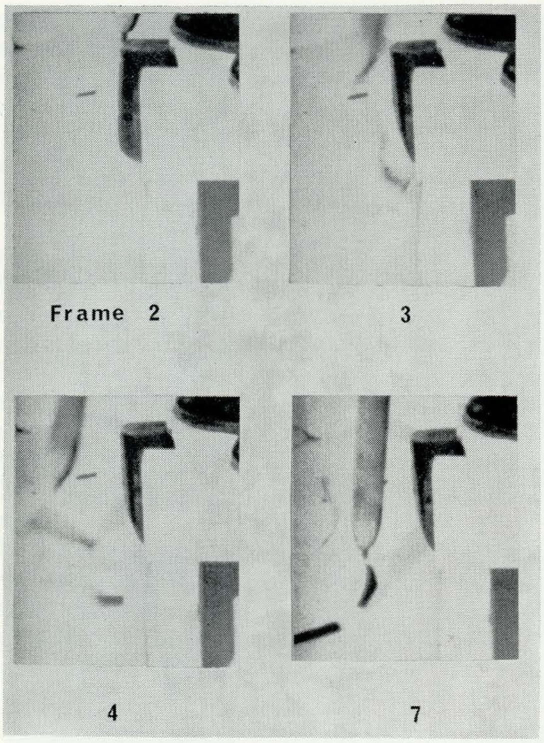

FIG. 14. Series of high-speed photographs, taken at 5,000 frames per second, showing removal of the distal end of the core. Frame 2 — The core is placed in the clamp with the crutch tip positioned on the platform and downward pressure being applied. Frame 3 — The blade has been detached from the core and appears as a blur just to the left of and slightly below the core. Note the change of position of the core in the clamp and the change of shape of the face of the core. The core was not properly secured in the clamp, and, when outward pressure was applied, the core tipped outward changing the angle of applied force resulting in excessive downward pressure and removal of the distal end of the core. Frame 4 — The blade has broken and appears as two blurs below the crutch tip and to the left of and beneath the core. Frame 7 — The two blade fragments are resting on the floor. The fragment just beneath the crutch tip is the distal end of the blade, the shape and heaviness of this portion showing that the distal end of the core has been removed. Compare the path of travel of the crutch tip in this series with the movements of the crutch tip in Figs. 11, 12, and 13.

the core, with the broken pieces spiraling as they become air-borne. This sort of miscalculation usually causes the core to be malformed, and the successive blades removed from that area will also be malformed.

If the end of the shaft vibrates in a succession of waves, the blade convulses and undulates, and this peculiarity is usually associated with an excess of outward pressure. It may be possible to overcome this by the use of a thicker staff or by placing a weighting medium on the shaft of the pressure tool.

High-speed photography has permitted the study of the platform area at the moment of contact by the pressure tip; it is this contact area which controls the thickness of the blades. Such photography has also been useful in studying the muscular motor habits of the stoneworker. These habits and involuntary movements were undetected until photographed at high-speed. Such movements are even more noticeable in direct percussion work, and these will undoubtedly be more detailed when further experiments have been made with this photographic technique.

By using close-up lenses, the camera has permitted one to observe all of the action and behavior of the material and to study this action either by motion or by single-frame stills. The enlargements projected on a screen allow minute examination of details that may be undetected when just watching an actual demonstration. The film is also helpful to the stoneworker, for it allows him to observe many details that he cannot see during manufacture. Should a platform crush, or should a flake hinge- or step-fracture, the cause and effect may be determined by closely observing what actually happened to set up this certain condition (Fig. 14). This allows the stoneworker to correct any miscalculations that may be causing these truncations.

These films will also give invaluable aid to better understanding the fracture of materials with isotropic qualities. They show very clearly the behavior of the cone and its relation to the prismatic blade. We are all familiar with the dropping of a pebble into a pool and the resulting regularity of the waves which are the result of the force with which the pebble hits the water. These concentric waves may be compared to a solid with the same isotropic qualities. Dropping a pebble in water is much like a percussion blow; when the pebble is slowly immersed in the water, no waves are evident, and this slow movement is much the same as applying pressure. Blades removed by pressure have an absence of concentric rings (undulations). Should the pebble strike a piece of glass, which has much the same properties as a heavy liquid, waves will also result, but they will be projected ahead of the pebble in the form of a truncated cone. This truncation will be of the same size as the surface of the glass contacted by the pebble. However, should the pebble be pressed on the corner of a block of glass vertical to the flat plane, a quarter of a cone will be removed. This fourth of a cone will remove the corner; at the same time, it will travel back into the block of glass at the same angle as the cone removed from striking vertically into the flat surface. The flake, however, will in no way resemble a blade removed from a polyhedral core.

The high-speed camera shows that, if the platform has been slightly freed or isolated by the removal of small flakes on each of its sides prior to blade removal, when the blade is pressed off the platform will act as the truncated part of a cone. The cone is then dislodged from the core by the application of outward pressure, and the downward force then removes a mass of obsidian, in the form of a blade, the full length of the core. The greater mass has been confined by the two ridges previously established on the face of the core, forcing the blade to move in the line of least resistance, and thus creating a long trapezoid with parallel sides. The elasticity of the material permits some bending. The angles of the cone are converted by the outward pressure until the angle of the cone facing the core is parallel to the side of the core bearing the two ridges which were established by previous blade removal.

The camera readily demonstrates how the angles of a cone can be converted by the application of the outward pressure. The angle of travel of the tip of the pressure tool after it leaves the core is the same as if one were to use percussion instead of the downward and outward pressure. The main difference in the two methods — pressure and percussion — is comparable to the effect of the pebble in water, as mentioned before, with the consequent production or nonproduction of concentric ripples, waves, or undulations on both the blade and the core. The more vitreous materials have less viscosity than the more granular materials; consequently, the waves in the glassier rocks tend to be magnified. When making a decision concerning, or a comparison of, the techniques used (i.e., pressure or percussion), the material must also be considered. Considerably greater amount of force is required to remove a blade by pressure than by percussion, which makes use of gravitational potential energy and which converts the intensity of the blow, upon striking the core, to kinetic energy. The use of percussion also has an effect of which I am aware, but which, at this time, I am unable to fully describe. That is, upon impact certain types of blows induce intense shock, even though the blow is light, and this causes the blade to part from the core with much greater ease than those struck with less velocity. This peculiarity is related to the elasticity of the material. I can think of only one example to illustrate this peculiarity, and that is to relate it to candy making. It would be impossible to break, by bending, freshly made warm candy that is still plastic; but, by giving it a sharp blow, it may be easily shattered. This same principle appears to be related to the type of blow I am trying to describe. Also, once a flake is started, or once a crack appears on the core to break the molecular attraction, the balance of the flake or blade may be removed with less force. This is, of course, characteristic of scoring glass before it is finally broken.

CONCLUSIONS

My experiments in prismatic blade-making have helped me reach some conclusions regarding the variable conditions that can be controlled by manual skill and the behavior and response of certain materials when subjected to stress. I have only admiration for the aborigine's skill in making near-perfect calculations of angles and in relating the combinations of forces necessary to repeatedly remove blades from cores with such accuracy and precision. Their exhausted cores are evidence of the perfection and control of all of these factors. An attempt to replicate these blades and cores will make one appreciate the required skill and control necessary to duplicate the cores and blades of the aborigine. No amount of theorizing by merely examining a flake or blade scar will give a true picture of these techniques; only by replicating can we change theory to fact. I am hopeful that the illustrations showing ancient man simply striking a block of obsidian with another piece of stone to remove a blade from a polyhedral core will be reconsidered.

Before we can reach a final and definite conclusion concerning the manufacturing techniques, the flake-scars of both the core and blades must be studied in minute detail. Not just one specimen, but many, and then every feature and characteristic of the aboriginal work must be duplicated. Only after years of experimenting, after the removing of thousands of blades, and after analyzing the results of these experiments, did I reach the conclusion that true replicas could be made by the pressure technique. These experiments have shown that blades and cores made by the use of pressure do have every quality and characteristic of most cores and blades found in Mesoamerica. This conclusion is based not only on my experiments but also on relating the aboriginal work to some of my pressure-worked replicas.

It is not difficult to examine an artifact and see the approximate direction in which force was applied; but, to determine how and by what individual or traditional technique the artifact was made involves actual working tests before final conclusions can be reached. Each technique characteristic of certain groups of men of prehistory may play an important part in their economy, and, therefore, I recommend to each analyst the personal act of fracturing stone.

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