THE ANCIENT ART AND CRAFT OF THE LAPIDARY

LEONARD GORELICK

This present issue of *Expedition*, like the previous one, is a special number devoted to the subject of the ancient lapidary. Together, they constitute the first time that the subject has been dealt with as a unified theme, from the work of Paleolithic Man, through that of the cunning craftsmen who made the first cylinder seals, to the spectacular jewellery of medieval and modern Islam, and the workshops of present-day India. All the papers will be given at a symposium entitled "The Ancient Craft and Art of the Lapidary," being sponsored by the Archaeological Institute of America, the National Endowment for the Humanities and the North Shore Society of the AIA. On behalf of the North Shore Society, I offer thanks to all who made the symposium possible and to Bernard Wailes, editor of *Expedition*, who made these special issues available.

Leonard Gorelick
Symposium Coordinator
North Shore Society of the
Archaeological Institute of America

The Symposium will be held at the New York Institute of Technology, Old Westbury, Long Island. It will take place on Saturday, November 21, 1981, from 9:30 to 4:00. For information write to Leonard Gorelick, 54-44 Little Neck Parkway, Little Neck, New York 11362.

PALEOLITHIC TOOLS

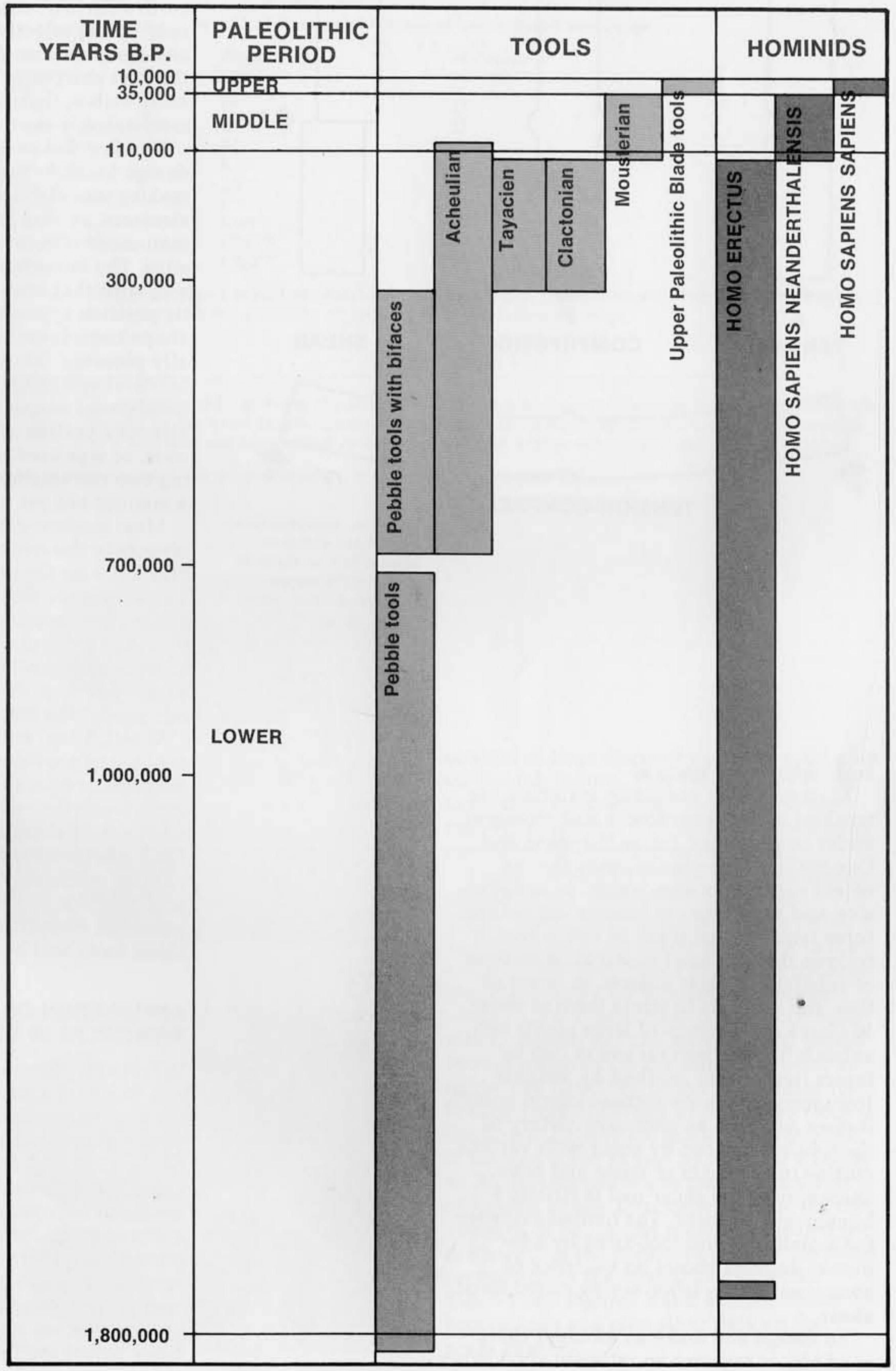
Some Design Considerations

JOHN S. KOPPER

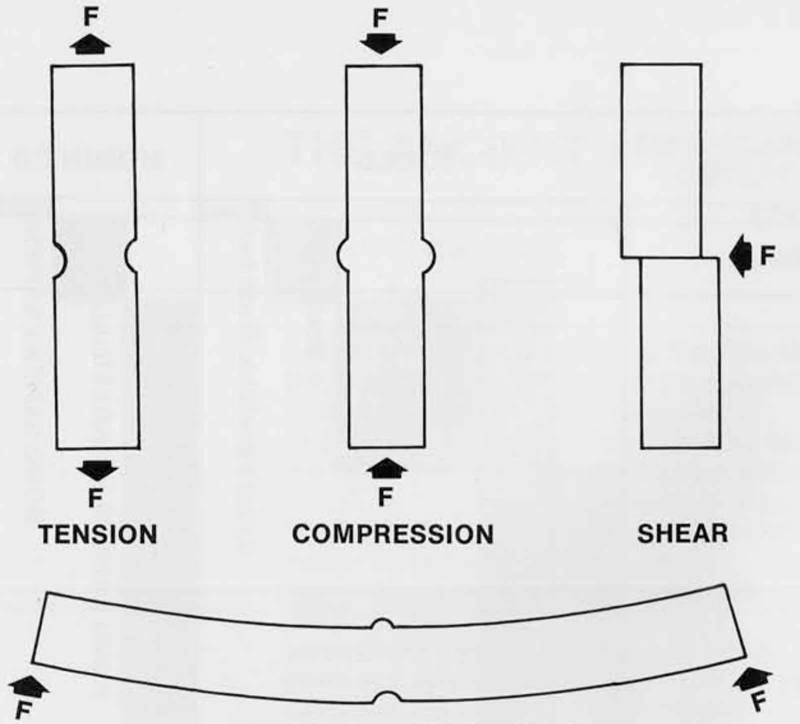
Paleolithic tools have seldom been analyzed from the design viewpoint. We know a great deal about how they were made and how they were used from ethnographic observations, experimental manufacture and microwear analyses. A 'mental template' is often invoked as the guiding principle in Paleolithic tool design and production: the finished tool conforms to a mental picture of what a proper tool for a specific purpose must look (and function) like. Yet, such a model ignores the physical constraints that the real world imposes on the designer-maker-used of such implements. First, I will investigate how Paleolithic people coped with such parameters as strength of materials, biomechanics, the scale effect and other engineering principles. Second, I will consider design advances in a time framework to see if a pattern emerges for technical innovation. Figure 1 gives data on the tools and people of the Paleolithic in a time framework.

TOOL DESIGN—TENSION, COMPRESSION, SHEAR

All natural substances fail mechanically in certain predictable ways, The earliest tool makers were aware of these and utilized them. A tree, an animal, a rock can be reduced to two or more pieces by mechanical stress in the form of tension, compression, or shear, or a combination of them. The forces producing these are



1
The Paleolithic Period with its subdivisions is shown for Europe, the Mediterranean and Sub-Saharan Africa against a time scale. The appearance and disappearance of human species and subspecies and of stone tool industries are shown at right.



2
Tension, compression and shear stresses shown left to right at top. Combination tension–compression stress shown below. F is a force resulting in a strain expressed in kilo./cm.^{2} of cross-sectional area.

schematized in Figure 2.

Most naturally occurring materials are weakest under shear forces and strongest under compressive forces (Laurson and Cox 1947: 9): gravity demands that an object support its own weight in compression and sometimes in tension; no natural force requires that it not be cut in two. It follows that the most economical method of subdividing most objects, in terms of time and effort, is to stress them in shear. We have no evidence of large plants and animals having been racked in two by levers (tension) or crushed by weights (compression) in the archaeological record. Rather, we have an exclusive history of them being reduced by shear with various cutting instruments of stone and bone. Discovery of the shear tool is strictly a human achievement. The limited evidence for toolmaking and tool-using by non-human animals shows no evidence of awareness of the labor-saving principle of shear.

To design and make an efficient sharpened object requires an intimate knowledge of tension and compression stresses. Siliceous stone, the hardest of all rigid materials found in abundance on the earth's surface, can be worked efficiently only by the selective application of tension and compression: this is why it produces the best sharpened objects (tools)—invariently stable; thermally, chemically and mechanically inert.

The first flaked siliceous pebble was the design breakthrough; thereafter, toolmaking was elaboration on a theme. Shear stressers, cutting tools, are the predominant man-made objects found at Paleolithic sites. The importance of the cutting edge was such that over the entire Paleolithic its position appears to dominate all other shape considerations, including 'asthetically pleasing' bilateral symmetry. When bilateral symmetry does occur, as with handaxes, I suspect it was to provide an alternate cutting edge by flipping the tool over, or was used point first at tasks requiring two converging sharpened edges, or in a manner not yet understood.

Most modern direct subdivision of objects in the environment, living or inert, still relies on the principle of shear. Bullets, knives, spears, fish hooks, guillotines, snares and garrotes render the living inert by shear stresses. Plows, harrows, harvesters, explosives, saws and chainsaws, picks, punches, drills, shovels, bulldozers, etc. render the inert manageable by shear.

Wood, bone, antler and horn are not capable of providing or sustaining a shearing edge comparable to that of silica oxide rock. Nevertheless, all may have been used during the Paleolithic period for tools with lower performance requirements, and their paucity in the archaeological record is probably due to their poor preservation potential. Hereafter, only the design of stone tools will be considered.

APPLICATION OF ENGINEERING PRINCIPLES IN STONE TOOL DESIGN

Probably the most impressive thing about any Paleolithic assemblage is the infrequent occurrence of failed tools. Unfinished pieces, discarded before completion, are common enough from all periods. Frequently the flaws that led to their abandonment are not even recognized by the archaeologist, but their designer-makers knew them. Worn-out tools, often resharpened to the point of non-utility, are also well known, but tools that failed at a critical task are not. Broken projectile and lance points are found occasionally but the context of their discovery usually precludes on-the-job failure. This fact implies much more than an intimate knowledge of the materials worked; it demands an extensive command of engineering principles.

From the earliest pebble tools, an appreciation of the 'scale effect' is present. Tools, particularly those used with force as in chopping, are scaled in weight to the height of the user. Since in a given population most males (or females) will range within a few centimeters in height of each other, choppers of the same general period should weigh much the same. They do, as subjective handling, or the more objective scaling from drawings, of handaxes from the Lower Paleolithic in Europe indicates. If the tool is too heavy, by as small a factor as X5, it is dangerous to the user in terms of broken bones, torn muscles, etc., for the strength of bones and muscles is scaled to the height of the person in exactly the same proportion as the weight he can wield. Table 1 and Figures 3 and 4 depict these proportions and give other data on the scale effect.

TABLE 1

The scale effect and the principle of similitude.

Linear size $\propto$ L Height, length, lever length, contraction length
Area $\propto$ L^2 Surface area, cross section, muscular force
Volume $\propto$ L^3 Mass, weight, scale of heart, blood and lungs

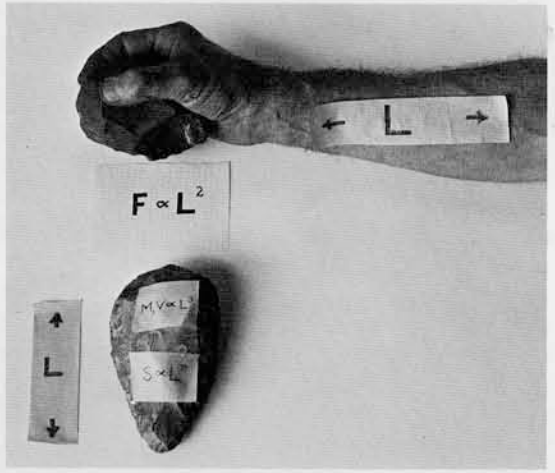
Quantity	*Physics*	*Biological*
Length	L	L
Surface	L^2	L^2
Volume	L^3	L^3
Mass	M	L^3
Time	t	L
Velocity	LT^{-1}	L^0
Frequence	t^{-1}	$1/L$
Force	LMt^{-2}	L^2
Energy	L^2Mt^{-2}	L^3
Power	L^2Mt^{-3}	L^2

Similitude: The principle of similitude establishes, for example, the relationship between the weight of an object and the structure supporting it in the following way:

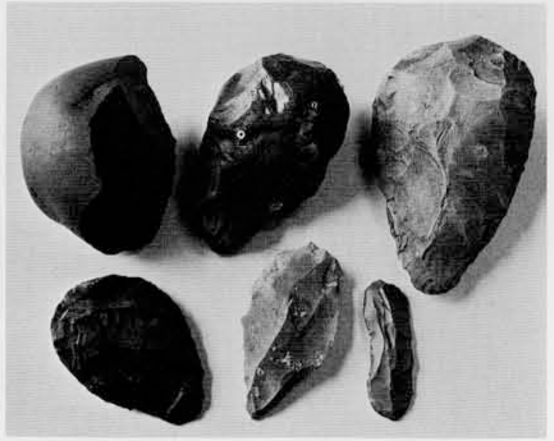
$$\frac{\text{Force}}{\text{Area}} \propto \frac{L^3}{L^2} \propto 1$$

In one example it governs the absolute height to which trees can grow (*ca.* 100 *m.*) before the weight of the extra length crushes the trunk. It can also be applied to calculate the weight of a tool that can be wielded in hand or on a haft before either the bone or haft is broken.

Note: $\propto$ is the symbol for proportionality, it does not mean equal to.



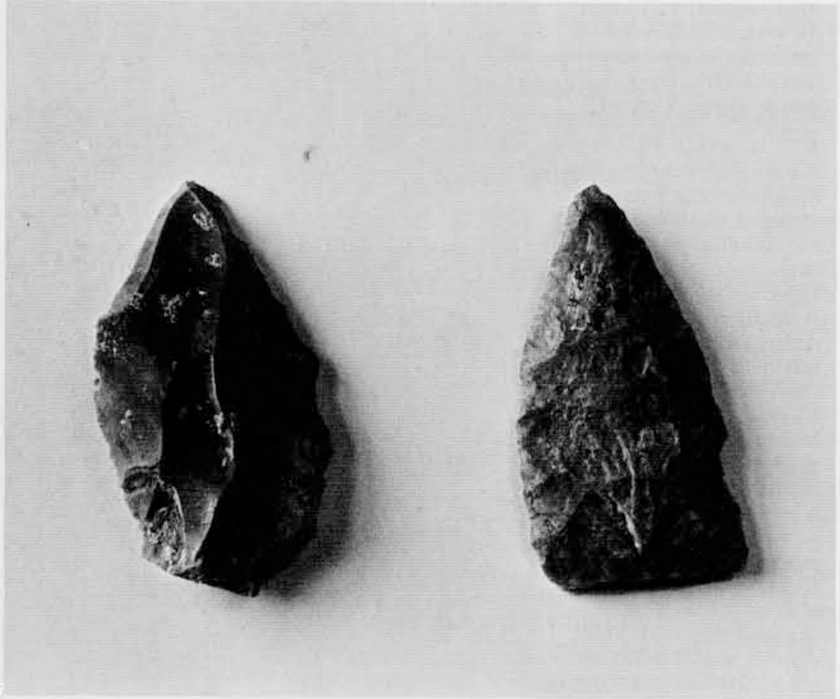
3
The scale effect. If L is any length measurement, in this case the length of the forearm, the force (F) is proportional ($\propto$) to L^2 as is the relative muscle strength of the arm wielding the tool. Tools of similar shape can be similarly analyzed to estimate stresses on them. If a biface (handaxe) has a length (L) its surface area (S) is proportional to L^2 and its weight (M) and Volume (V) are proportional to L^3. (Photograph, Allan Barber)



4
A major theme from the Middle through the Upper Paleolithic is a reduction in the size of tools (top row, left to right, Pebble tool, early Acheulian, late Acheulian; bottom row, left to right, Mousterian, Mousterian and Upper Paleolithic blade tools). Accounting the scale effect on the simplest level indicates a replacement of gross hand-arm cutting methods by finer hand-finger manipulation and/or mechanically assisted use with handles or shafts. (Photograph, Allan Barber)

5

Middle Paleolithic point has flat flake scars with smooth, gradual flake intersections. This design reduces stress buildup at such intersections. (Photograph, Allan Barber)



6

Middle Paleolithic (Mousterian) point at left has curved edges that increase its cutting edge length over the Upper Paleolithic (Solutrean) point at right. If both are lance or spear points, the older is superior in this regard. (Photograph, Allan Barber)

Similarly, the tool itself must be proportioned to accommodate the scale effect. Edge angle, shape and length vs. tool weight vs. tool cross sectional area are all critical in a cutting tool of siliceous rock if the edge is not to fracture prematurely. As mentioned above, there is some indication that the Lower Paleolithic designers of chopping tools were aware of the scale effect; however, they seem to have left extra large safety factors in their products.

Inverting the principles of the scale effect should permit us to estimate biometric data for early tool users from the scale of their tools.

Friction is a major factor in Paleolithic tool design. Sliding friction, as operative during cutting, piercing and drilling work, is proportional to the force resisting penetration but independent of the area of contact with the cutting tool, in the following way:

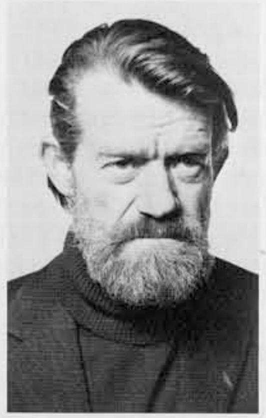
$F = \mu N$

where F = force required for penetration
N = force resisting penetration
μ = coefficient of sliding friction.

μ for wood against wood is about 0.35, for stone against stone about 0.65 and stone against wood about 0.40. Relative roughness of the two surfaces in contact is a factor as is the deformation of the softer object by the stone tool. For the latter reason, any flaking, primary or secondary, is always a disadvantage, but the finer the flaking the less the disadvantage. On the other hand, the extremely fine surface obtained by chipping cryptocrystaline rocks like flint and chert may have compensated for the negative effect of flaking and thus was a deliberate design trade-off.

Flaking is advantageous in other ways. It is often assumed that conchoidal fracture was exploited only to reduce bulk easily and produce an immediately useful sharp edge. Other advantages accrue. With flaking, the opaque cortex is removed to expose to view cracks and flaws—areas of incipient failure. Surface cracks, however fine, serve to concentrate tension, compression and shear stresses as do any abrupt, angular changes in cross sectional area. Judicious flaking reduces such abrupt angles in the raw stone, preventing stress buildup at these points. The gradually thinning contours of tools from Early Acheulian times onward may have been for this purpose alone and have nothing to do with aesthetics of shape. The finer flaking achieved in later Paleolithic times further reduces surface relief and, thus, distributes stresses.

On a finer scale, the flake scars left by properly chipping material with a conchoidal fracture are advantageous in themselves. The intersections of flake scars in these rocks have gently curving rather than angular profiles. This reduces stress concentration at these intersections in the same way that radial rather than angular corners are machined or cast into metal components of industrial equipment subject to high stress. Taking this line of reasoning one step further, one wonders if a major reason for the invention of Levallois flakes was not just this. These flakes have a minimum number of scars and the scars themselves are very flat with very gentle intersections (Figure 5). This is optimal design from the point of view of strength and minimum friction for a stone tool used in critical performance under high impact loading. Certainly the edge shapes of these points bespeak such design foresight. They provide maximal cutting edge with minimal point length by using curved instead of straight edges (Figure 6). Point length is, of course, crucial when a brittle material is levered during thrusting; it must be as short as possible consistent with deep penetration (see Figure 3).



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