THE INTELLIGENCE OF LATER ACHEULEAN HOMINIDS

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This article uses Piagetian genetic epistemology to characterise the intelligence of later Acheulean hominids. In particular the Piagetian concepts of reversibility and conservation are used to assess the spatial concepts used by the hominids who manufactured the artefacts from the Isimila Prehistoric Site, Tanzania. It is concluded that these artefacts required the organisational abilities of operational intelligence and that, therefore, the hominid knappers were not significantly less intelligent than modern adults. Such a conclusion indicates that increasing intelligence has not been a significant factor in cultural evolution for at least the last 300,000 years. Concluding that later Acheulean hominids employed operational thought also suggests that such cultural realms as kinship and cosmogony may have been more complex than archaeologists have heretofore imagined.

Introduction

This article attempts to characterise the intelligence of later Acheulean hominids. It uses as evidence for intelligent behaviour the stone artefacts from the Isimila Prehistoric Site, Tanzania. The focus is strictly on hominid intelligence. No attempt will be made to explain the function of stone tools or to identify the motives of the hominid stone knappers. The geometry of stone tools will be used to identify the ways in which the hominids organised certain actions, such organisation being indicative of overall intelligence.

In order to characterise intelligent behaviour of any kind it is necessary to have a theory of intelligence. This article employs the genetic epistemology of Jean Piaget. There are two reasons for this choice. First, genetic epistemology is a developmental theory of intelligence that encompasses all intelligent behaviour and is consistent with, indeed requires, the evolutionary perspective. Second, the data employed by Piaget include spatial and geometric concepts that can be used in the interpretation of artefacts. Clearly such a theory has potential for use in archaeological interpretation.

Some may argue that characterisations of hominid intelligence are at best speculative exercises of little relevance to serious interpretations of prehistory. I would disagree. Intelligence is a crucial variable in the evolution of culture. Modern culture depends, ultimately, on a sophisticated ability to organise technological, social, and symbolic phenomena. It is axiomatic, from the evolutionary perspective, that such an ability has evolved. But when was modern intelligence achieved? If it was achieved only 30,000 years ago, many of the cultural developments of the Lower or Middle Palaeolithic could be attributed to or at least correlated with increasing intelligence. But if essentially modern intelligence was achieved 300,000 years ago, as I argue here, then the processes of culture change since then must be conceived differently. The two

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scenarios present fundamentally different problems of interpretation for the palaeolithic archaeologist.

Most interpretations of prehistoric hominid intelligence are based on the fossil record or on comparative data. Both kinds of data have serious drawbacks. Fossil data can tell us something about brain morphology and size but until we better understand the relations between morphology, physiology, and behaviour, fossils will remain poor indicators of intelligence. Comparative data allow us to isolate what is peculiarly human about human intelligence but they cannot be used to reconstruct the actual details of development. Nonhuman primates do not, after all, necessarily represent stages in the hominid phyletic line.

Interpretations of intelligence can also be made through the archaeological record. Archaeological data are the result of behaviour that was organised by an intelligence. An appropriate theory of intelligence enables us to investigate the intelligence of prehistoric hominids. Only one aspect of Piagetian theory, the characterisation of adult intelligence, will be employed here. Nevertheless, for those unfamiliar with Piaget's work it is necessary to discuss briefly the scope of genetic epistemology.

Theory

Genetic epistemology is a structural theory. It defines the structures of any intelligence in terms of the organisational principles actively employed by an organism. These principles, termed 'regulations' by Piaget, organise in one form or another the actions of all organisms, from the food-searching action of amoeba to the internalised action of human thinking (Piaget 1974). To say that an individual or organism is more intelligent than another is to say that it is capable of organising its behaviour in a more complex fashion. Such a definition of intelligence can encompass such diverse phenomena as biological auto-regulation and propositional logic (Piaget 1974). Intelligence from this perspective is not a qualitative determinant of humanity, but a set of organisational principles employed by all life. Modern adult human thinking is merely this set of organisational principles in its most sophisticated form.

Genetic epistemology is quite general in scope and has some rather ambitious aims. It is not, as some readers may think, exclusively or even primarily a theory of child development. The development of thinking in children has been the primary empirical base for the theory for a very good reason.

> The fundamental hypothesis of genetic epistemology is that there is a parallelism between the progress made in the logical and rational organization of knowledge and the corresponding formative psychological processes. Well, now, if that is our hypothesis, what will be our field of study? Of course, the most fruitful, most obvious field of study would be reconstituting human prehistory—the history of human thinking in prehistoric man. Unfortunately, we are not very well informed about the psychology of Neanderthal man or about the psychology of *Homo siniensis* of Teilhard de Chardin. Since this field of biogenesis is not available to us, we shall do what biologists do and turn to ontogenesis. Nothing could be more accessible to study than the ontogenesis of these notions. There are children all around us. It is with children that we have the best chance of studying the development of logical knowledge, mathematical knowledge, physical knowledge, and so forth (Piaget 1970*a*: 13).

Piaget has described an ontogenetic sequence of stages, each stage presenting a characteristic set of regulations that govern thinking. It is only Piaget's characterisation of the final ontogenetic stage, that of adult thinking, that is of particular interest here. This is the stage of 'operational thought'. Operational thought organises phenomena by means of regulators called operations. Because operations regulate internalised action—i.e., action which occurs only in thought—they possess some powerful qualities and are considered by Piaget to be 'perfect regulations' (Piaget 1970*b*: 15). 'What this means is that an operational system is one which excludes errors before they are made, because every operation has its inverse in the system (e.g., subtraction is the inverse of addition, $+n-n=0$) or, to put it differently, because every operation is reversible, an "erroneous result" is simply not an element of the system (if $+n-n\neq 0$, then $n\neq n$)' (Piaget 1970*b*: 15).

The two fundamental regulators of operational thinking are reversibility and conservation. They can be recognised in the organisation of the behaviour of modern adults and, as I will show, in the behaviour of later Acheulean hominids. 'Operations ... are actions coordinated into reversible systems in such a way that each operation corresponds to a possible operation that renders it void' (Piaget 1971: 36). There are two kinds of reversibility—reversal by inversion and reversal by reciprocity. Inversion (or negation) requires inverting a transformation and by so doing returning to the starting point, e.g., subtracting a given number after it has been added ($+A-A=0$). Reversal by reciprocity is simply a reversal of order (Piaget 1970*a*: 22). A transformation combined with its reciprocal yields an equivalence (e.g., $A\geqslant B$ and its reciprocal $B\geqslant A$ results in $B=A$). An extended example of regulation by reversibility is appropriate. The one most often cited by Piaget is that of the 'quaternary group' (Piaget 1960; 1970*a*; 1970*b*; 1971; 1972).

An individual is shown a moving object that is intermittently starting and stopping. The stopping is accompanied by the lighting of a bulb. The question concerns how this individual comes to understand the relationship between the two phenomena. The lighting of the bulb could cause the object to stop (I will call this relation A). This would be disproved if the bulb ever lights without the object stopping (relation B). Alternatively, the stopping of the object could cause the bulb to light up (relation C). This in turn would be disproved if the object stopped without the bulb lighting (relation D). What is significant here is that, if the individual does approach the problem in this manner, he is coordinating two kinds of reversibility—inversion and reciprocity. The hypothesis that the light caused the object to stop (A) is disproved by inversion (B), i.e., the light came on but the object did not stop. The individual then hypothesises the reciprocal situation (C), i.e., the stopping of the object lights the bulb. This can in turn be negated (D). Interestingly, this inversion, the object stopping without the bulb lighting, would not disprove the original hypothesis (A) because if the object stops without the bulb lighting it does not mean that lighting the bulb would not stop the object. The negation of the reciprocal is, therefore, a corollary of the original hypothesis. This entire situation can be formalised into symbolic logic.[1] However, it need not be and certainly is not so conceived by the individual who approaches the problem casually. He employs the two kinds of reversibility as a matter of course, in his actual behaviour. The regulation of this kind of thinking, this structure, is 'perfect' in the sense defined above because all contingencies are covered by the organisation, i.e., all possible relations of light and object are considered. Errors are excluded.

Reversibility renders thought capable of conservation (perhaps Piaget's best-known concept). Algebraic transitivity is an example of conservation. If '... A = C because A = B and B = C, it is because some property is conserved from A to C; and on the other hand, if the subject accepts as necessary the conservations A = B and B = C, he will infer from them A = C by the same arguments' (Piaget 1972: 36). Here reversal is by reciprocity. On the surface transitivity may not seem a very complex concept yet it requires reversibility in thinking, the ability to return mentally to A. Without such reversibility A cannot be related to C. Conservation provides operational thought with certain important characteristics. One is the ability to return to a starting point within thought. Another related characteristic is the ability to pre-correct errors, a consideration of transformations and their reversal before a problem is undertaken. This is an obvious advantage when compared to trial-and-error solutions where corrections can only be made after errors have occurred. This principle of conservation is essential to all of the operations of adult thought.

Operational thought can be recognised in the actual behaviour of individuals and it is this aspect that renders Piaget's characterisation so useful for prehistory. Adults typically organise behaviour by means of reversibility and conservation. Kinship systems, for example, are based on classification, which can be formalised $A + A' = B$, $B + B' = C$, etc. (e.g., in a unilineal descent system collaterals are a sub-set of the descent group). Now classification requires reversibility, in this case by means of inversion ($B - A' = A$). Kinship systems also require conservation for if individual A is related patrilineally to B and B is so related to C then A and C are also patrilineally related. Without reversibility and conservation, complex kinship systems would be impossible. The concepts defined in kinship systems are concepts relating discontinuous entities and are termed 'logico-mathematical thinking' by Piaget. Such relations are generally not visible archaeologically, especially in the Palaeolithic. Operations, however, are also employed in concepts internal to objects, most especially in object geometry. This organisation of relationships internal to single objects is termed by Piaget 'infra-logical thought' and it is this kind of thinking that can be recognised in stone artefacts.

Chipped stone artefacts are manufactured by organising the actions of flake removal. The removal of an individual flake is a simple action requiring only minimal organisational ability. In order to manufacture all but the most rudimentary stone tools, however, flake removals must be related to one another in a fashion yielding the appropriate configuration or pattern. If a stone artefact presents a pattern of flake removals that could only have been organised by means of reversibility and/or conservation, then it must be concluded that the maker possessed operational intelligence. I will show that the later Acheulean artefacts from the Isimila Prehistoric Site present such patterns.

One reservation concerning any conclusion reached about the intelligence of prehistoric hominids must be considered before discussion of the archaeological data. It is possible to reconstruct only the minimal necessary competence of any prehistoric hominid. The intelligence reflected in the patterns of stone artefacts need not represent the most complex abilities of the hominids. Historic Tasmanians, for example, possessed a very simple stone tool technology yet no one would equate their intelligence with that of Plio-Pleistocene hominids. As long as conclusions must be based on only a small range of intelligent behaviour, that of tool making, the possibility of underestimating capability is fairly great. Even if the maker of an Oldowan chopper had been capable of understanding the Heisenberg uncertainty principle, the chopper itself would require only a much humbler competence and it is this competence that the archaeologist would infer. Despite this reservation archaeological data remain the only direct evidence available from which we can approximate the evolution of human intelligence. With reasonable care the application of the theory described above should still provide a useful, if not exhaustive, characterisation of the intelligence of later Acheulean hominids.

Analysis

What follows is an analysis of one set of stone tools from a later Acheulean site. The artefacts used all come from Sands 1 and 3 of the Isimila Prehistoric Site. This site has not been securely dated but appears on the basis of ^{230}Th and ^{213}Pa determinations to date from somewhere between 330,000 and 170,000 years ago (Howell *et al.* 1972). The precise date is not crucial for the present discussion. On the basis of this rough date and the morphology of the artefacts Isimila is generally considered to be a later Acheulean assemblage. The analysis itself will consider attributes of the internal geometry of the artefacts, attributes that reflect the infra-logical regulations respected by the maker. Following Piaget's work with ontogenetic data three kinds of geometry will be considered: topology, projective geometry and Euclidean geometry. Each of these geometries employs a different set of axioms (when formalised) and a different set of criteria for evaluating the equivalence of figures and objects. In some respects topological geometry employs the simplest relations, e.g., proximity and enclosure. Nevertheless, topological, projective and Euclidean geometries each encompass relations that require operational regulations.

Four specific kinds of operational spatial organisation were applied in the manufacture of the Isimila artefacts—whole–part relations, qualitative displacement, spatio-temporal substitution and symmetry. Each of these infra-logical operations requires reversibility and conservation. Each is characteristic of adult thought and absent from the organisational repertoire of preoperational thought (Piaget 1960; Piaget & Inhelder 1967). I will now discuss each of these operations and present, in turn, the artefactual geometries requiring each particular kind of organisation.

1. *Whole–part relations.* This operation organises the addition of parts into the single complete object. It requires the ability to conceive of an object as a continuous whole made up of potentially separable parts which must bear

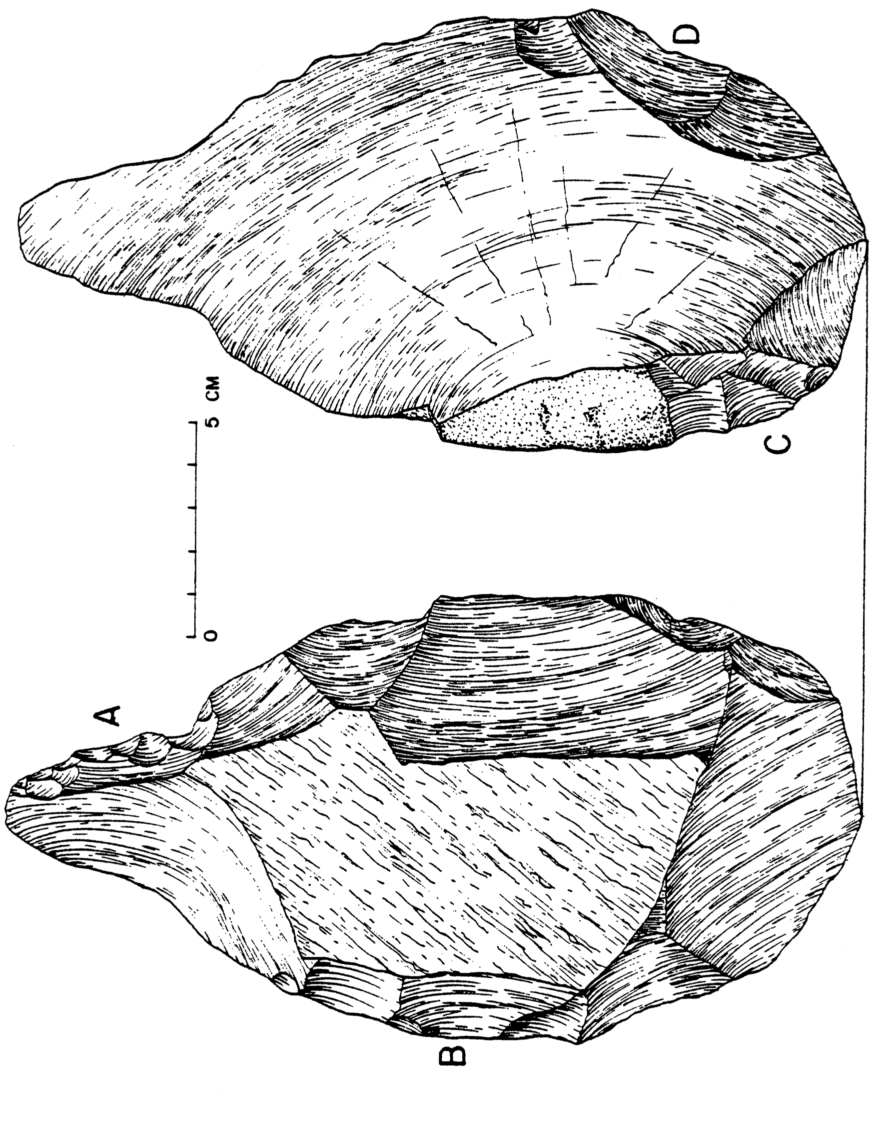

FIGURE 1.

specific relations to one another in order for the object to exist in its current configuration. To cite an obvious example, it is the relation of bricks which produces a building, not the simple accumulation of bricks. This relation of whole to parts is reversible by means of inversion. When an individual conceives of a project involving an object, he can plan the end result by combining, in thought, the potential parts into the whole. He can, of course, abandon this plan—a reversal to the starting point—and combine the parts in a completely new fashion. Such planning behaviour requires the reversible organisation of whole–part operations. This is the infra-logical equivalent of logico-mathematical classification ($A+A'=B$, $B+B'=C$, etc.) because separate parts are combined in an additive fashion to create a whole.

The bifaces indicate that the Isimila hominids were able to relate a whole to its parts in operational fashion. The amount of retouch on bifaces makes them especially informative because it indicates that their shape is likely to be the result of intention and, therefore, to reflect conceptual abilities. An example is presented in fig. 1. This biface has recognisable bilateral symmetry, an aspect that of itself has no bearing at this point in the discussion. What is important is the manner in which this shape was achieved. The artefact demonstrates what can be termed 'minimal trimming'. This means that the shape seems to have been achieved by a minimal amount of retouch. Here the symmetry has been created by four short sections of retouch (A, B, C, and D) which are not contiguous. In order to do this the maker had to have a competence in the relation of whole to parts. It is the way in which the four sections of retouch have been placed relative to one another that has produced the overall shape. The maker must have been able to conceive the desired shape in terms of potential constituent elements, in this case flake removals, and then combine these elements in additive fashion into a finished whole. This artefact could not have resulted from trial-and-error shaping (a pre-operational means of organisation). In trial-and-error shaping flakes would have been contiguously removed until an acceptable shape had been achieved. Such an approach could not anticipate an end result in terms of a minimal amount and position of retouch because such anticipation requires reversibility. The minimal and discontinuous retouch in this example indicates that the knapper anticipated the final shape and knew precisely what had to be done to achieve it. Such analysis of whole into parts is one of the most sophisticated of topological relations and, as we have seen, requires reversibility in thought. It attests to the operational competence of the maker. This biface is not an isolated case for there are several examples of minimally trimmed bifaces in the Isimila assemblage (especially from the G23 locality).

2. *Qualitative displacement.* In infra-logical organisations this is simply the ordering of placement or positions such that each element is situated in some specific and reversible relation to neighbouring elements, the result being a series. This differs from the preceding operation in that it regulates elements not as they relate to a conceived whole but as they relate to each other. To qualify as operational regulations the relations must, of course, be reversible. Here reversal is by reciprocity of the actual spatial relationships. An

arrangement of elements according to size requires such operational regulations. Each element is positioned according to its size relative to each of its neighbouring elements. Because the size relationship is reversible and conserving, if element A is smaller than B and B is smaller than C, then A must be smaller than C, even though A and C are not adjacent and cannot be directly compared. For a new element, say D, to be placed within such an ordering, it need not be compared to all previous elements because, of necessity, if D is larger than C it is also larger than A and B due to the transitivity of the reversible relations. This operation is the infra-logical equivalent of logico-mathematical seriation, e.g., $A < B < C$.

Operational qualitative displacement is difficult to recognise in artefacts because reciprocal reversibility in the placement of elements can rarely be identified. However, a few examples do exist in the Isimila assemblages which suggest this competence. These are examples of intentionally straight edges. The straight line is a projective figure. Projective geometry is a geometry of perspective in which a shape varies according to the source of a projection or the viewpoint of an observer. Certain aspects of projective figures (most notably straight lines) must remain constant for the figures to be equivalent. A straight line is a projective figure because all the points on the line must be related to a constant viewpoint. When a straight line is viewed from the appropriate position the terminal point of the line masks all the subsequent points and the entire line appears as a point. Actual sighting, of course, is not necessary but the equivalent projection is necessary, even if imaginary. Each point on a straight line is related by this projection to all the other points on the line in reversible fashion. If point D is 'in line' with points C and B, and C and B are 'in line' with A, then D is also 'in line' with A because of the reciprocal reversibility of the relation 'in line'.

What is true of straight lines must also be true of the straight aspects of artefacts, but only if the straightness is clearly the result of intention. This 'if' is very restrictive. Straight edges are fairly common on artefacts yet straight edges that are clearly intentional are rare. It might be tempting, for example, to consider cleaver bits as palaeolithic straight lines. Cleavers, however, are not as a rule manufactured with direct attention to the bit. The retouch and attention to shape is often applied everywhere but the bit, which remains a natural edge. The shape of such an edge is not demonstrably intentional. In order to argue about competence in straight lines the edge in question must be retouched and the retouch must have considerably altered the natural shape of the edge.

The artefact in fig. 2 possesses such an edge. Both faces of the original flake have been retouched to yield a remarkably straight edge. The edge is also straight in profile. The extent of the retouch suggests that the original shape of the edge has been considerably altered, i.e., flakes had been removed in such a way as to produce an artificially conceived shape, in this case a straight edge. The significance of this straightness lies in its artificiality for in order to produce such artificial straightness the knapper had to have related each flake removal to all of the others and also to a single stable point of view. In other words, each flake removal had to be 'in line' with all the others in relation to

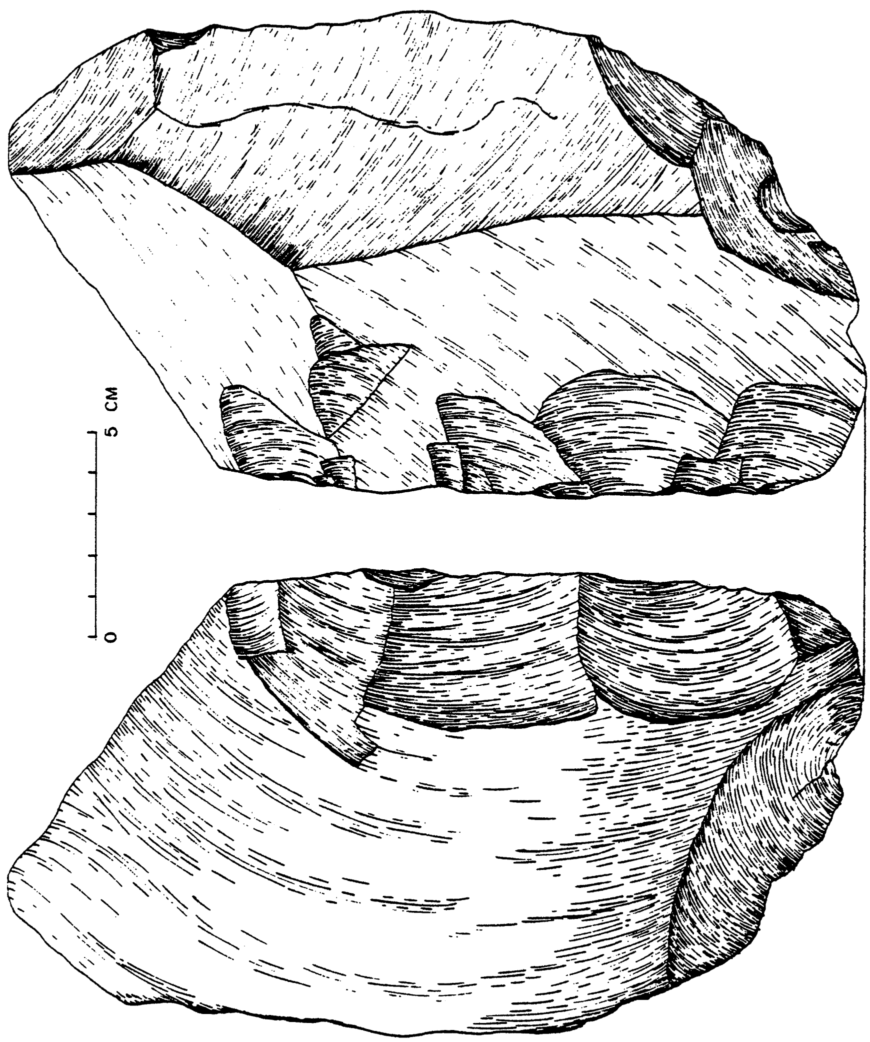

FIGURE 2.

some viewpoint. Even if this viewpoint consisted at times of actual sighting along the edge, the placement of flake removals could only be effective if all were related to that viewpoint, a viewpoint which, of course, had to be conserved in the knapper's imagination during the actual flaking process. As we have seen, such a spatial organisation requires reciprocal reversibility and can be considered an example of the infra-logical operation of qualitative displacement.

3. *Spatio-temporal substitution.* This operation requires an understanding of the potential interchangeability of relations that results in an equivalence. An example of such interchangeability is the ability to recognise familiar landmarks that are approached from a new direction. The landmark can be recognised only because certain familiar elements are rearranged into a new but equivalent configuration and new elements are substituted for familiar ones which are no longer visible. The result is the same whole—the landmark—but it has been constructed in quite a different manner. Like the first operation, spatio-temporal substitution deals with composition of wholes and the relation of elements to the whole and, like the first, is reversible by inversion. Its parallel logico-mathematical operation regulates equivalent inclusions in classification such that $A_1 + A_1' = A_2 + A_2' = B$.

This infra-logical operation of spatio-temporal substitution is attributable to Isimila hominids on the basis of the regular cross-sections of bifaces. Most of the cross-sections of a biface could not be directly perceived by the knapper because he could not 'see through' the external surface to the configuration of a planar intersection, e.g., one of the oblique intersections. How, then, can such cross-sections be made to conform to a desired shape? The relations between the elements, in this case flake removals, constitute the shape of the cross-section. During flaking the modification of the surface to regularise the cross-section from one point of view must not be allowed to ruin other cross-sections, most of which are not directly observable. Trial-and-error flaking is again out of the question because the majority of cross-sections cannot be visually checked for errors. These unobservable cross-sections must, therefore, be for the knapper purely mental constructs, constructs organised by means of spatio-temporal substitution. The observable effect of flaking must be translated into effects on viewpoints that are unavailable. This is again a matter of projective geometry. The knapper must construct unavailable viewpoints from available viewpoints by constructing mentally the rearrangment of elements and relations which would constitute the cross-section, if it could be observed, much as the traveller reconstructs landmarks approached from a new direction by rearranging familiar elements and substituting new ones. Moreover, a regular biface presents an essentially infinite number of regular cross-sections, all but a few of which must be constructed by means of spatio-temporal substitution.

Figure 3 presents one of the fine handaxes from Sands 1 at Isimila. The artefact has bilateral symmetry in plan, profile, and in cross-section. The cross-section was taken by means of a template at the point of maximum width. It is clear from the figure that any cross-section, taken at any angle of intersection,

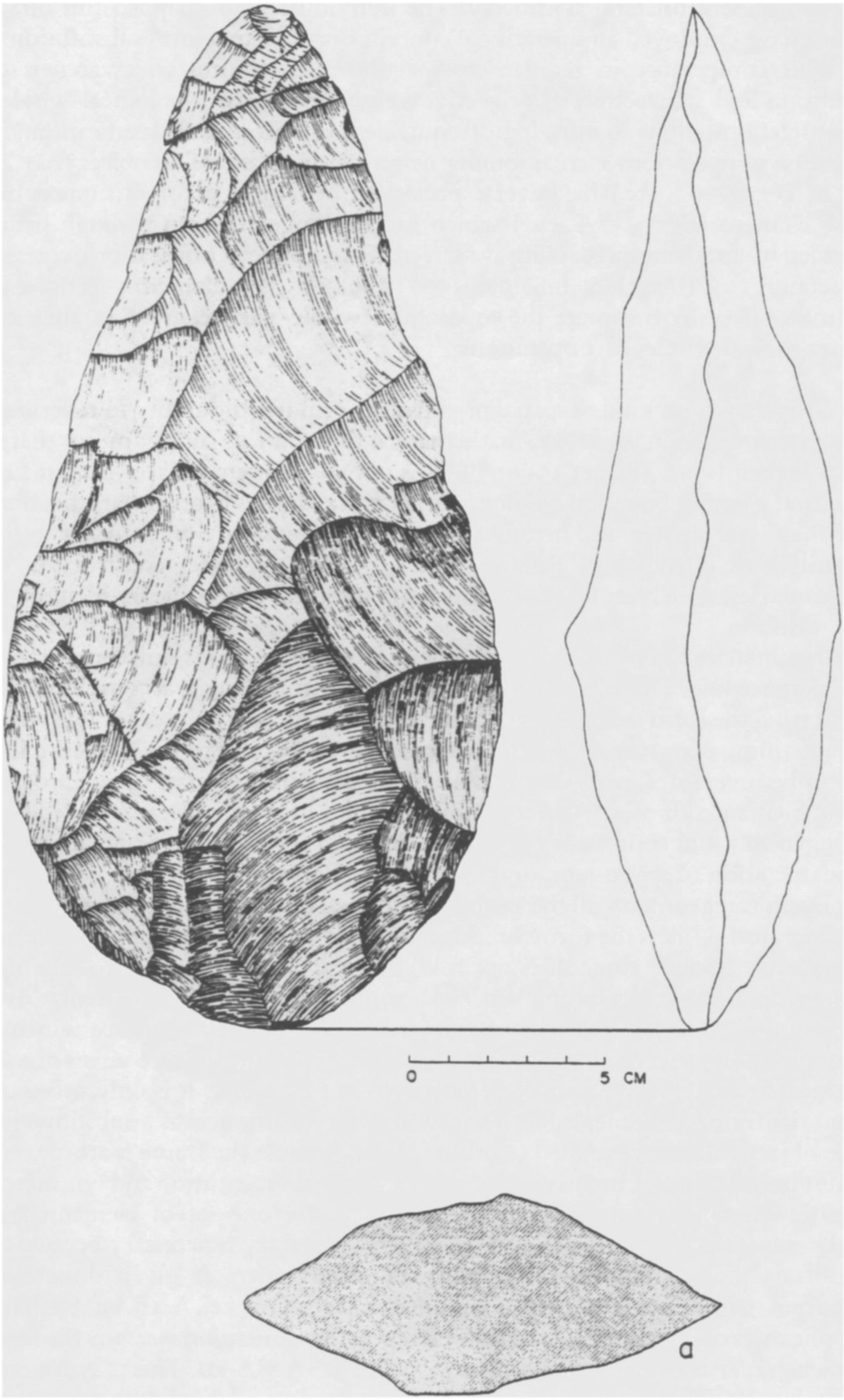

FIGURE 3.

would present bilateral symmetry. The individual who knapped this biface must have employed an operational concept of spatio-temporal substitution.

This competence in regular cross-section also requires an awareness of addition and subtraction of projective veiwpoints. Like topological whole–part relations, this is an infra-logical equivalent of operational classification. 'In the case of operations such as joining neighbouring parts of an object ($A + A' = B$, $B + B' = C$, etc.) the reverse projective operation involves suppressing one element ($B - A' = A$, etc.) which can no longer be seen through being hidden by another object acting as a screen. This subtractive operation expresses a section ...' (Piaget & Inhelder 1967: 469). The regular cross-sections of Isimila bifaces corroborate the topological whole–part relations in attesting infra-logical whole–part operations.

4. *Symmetry*. This kind of spatial organisation requires the ability to reverse an equivalent relation. In logico-mathematical thought this simply means that if $A = B$ then $B = A$ (Piaget 1960). (This is not as rudimentary as it may at first seem. If a young boy who has one brother is asked if his brother has a brother, he may well answer 'no' because he 'knows' there is only one brother in the family.) In infra-logical thought this operation regulates construction of symmetries, which are reversals of spatial series. It is reversible by reciprocity of relations.

Symmetries can be most easily recognised when a form is 'mirrored' across a reference line. This is bilateral symmetry. The mirroring is accomplished by inverting the form from one side of the reference line onto the other side while maintaining congruency. All the distances perpendicular to the reference line must be reversed, e.g., $A \rightarrow B = B \rightarrow A$. This is, of course, reversal by reciprocity. But bilateral symmetry is even more complex than this because it requires congruency and congruency itself requires both the symmetry operation and the operation of spatio-temporal substitution. For two forms to be congruent in Euclidean geometry all the analogous internal dimensions of the forms must be identical. Unless the forms are superimposed (clearly impossible in artefact symmetry because stone does not fold) some arbitrary means of comparing dimensions must be employed, i.e., some form of measurement. Any measurement requires the use of some arbitrary frame of reference which is not physically part of an object. Such a frame of reference often consists of a set of standard intervals (e.g., inches) but this is not necessary. It is only necessary that the frame be conservable. Such an arbitrary frame acts as a substitute for the object and can be applied to other objects. Because the frame is arbitrary it must be constructed, in this case by spatio-temporal substitution and symmetry. Spatio-temporal substitution is necessary because one set of elements and relations is substituted for an equivalent set. Symmetry is necessary because an arbitrary frame requires reversibility of serial order. A given dimension internal to an object is in itself an asymmetrical relation, i.e., $A \rightarrow B$, but with the application of an arbitrary frame of reference, this dimension *measures* the same when traversed from either direction, hence $B \rightarrow A = A \rightarrow B$. This is symmetry of relations. The creation of congruency, indeed of all Euclidean geometry, requires the application of an arbitrary and internally symmetrical frame of reference. In bilateral symmetry the congruency of form itself requires symmetry. The mirroring of forms again requires symmetry. Clearly, bilateral symmetry would be impossible without the organisational qualities of operational symmetry.

Symmetry is a quality easily recognisable in some artefacts, perhaps too easily so. Symmetry is so much a part of the everyday world that it is second nature to see it where it does not exist. It could perhaps be considered a 'good Gestalt', especially for Western man. Human faces are an excellent example. True metrical symmetry is never present yet we all perceive faces as being symmetrical. This immediately brings up the matter of perception and conception for, at first consideration, it is common sense to conclude that a concept of symmetry is generalised from perceptions of nature—faces and bodies especially. If this were true children would attend to symmetry as soon as they possessed the motor coordination to enable drawing. But they do not, the earliest drawings attending at most to topological relations (Piaget & Inhelder 1967). Children do not attend to symmetry until they have achieved an understanding of Euclidean relations. Once this occurs, the concept of symmetry can be applied to perception and figures can be recognised as such. Vaguely symmetrical artefacts may represent not a concept of symmetry on the part of the hominid knapper, but a concept of symmetry on the part of the archaeologist. Since this study is concerned with conceptual abilities of early hominids, not of archaeologists, it is important to avoid a too willing acceptance of an artefact as symmetrical.

Figure 3 presents unequivocal bilateral symmetry. A congruent form has been reversed across an imaginary midline. Moreover, there is symmetry in plan, profile and cross-section. A competence in congruence, with the necessary infra-logical operations of spatio-temporal substitution and symmetry of relations is clearly a prerequisite for the manufacture of this artefact.

Conclusion

This analysis of the geometry of Isimila artefacts demonstrates that the later Acheulean hominids employed in their stone knapping the infra-logical operations of whole–part relations, qualitative displacement, spatio-temporal substitution and symmetry. These complex geometric relationships cannot have been accidentally imposed. It is therefore necessary to conclude that operational intelligence is the minimal competence attributable to these hominids. Does this mean that the thinking of these hominids was equivalent to that of modern humans? In terms of organisational ability I believe the answer to this question must be yes.

Many will argue at this point that there is an obvious difference between the competence necessary to conceive and manufacture a symmetrical biface and that necessary to conceive, for example, $\sqrt{-1}$. I would counter that the difference is neither great nor necessarily relevant to a comparison of prehistoric and modern humans. Piaget does distinguish between two sub-stages of operational thought and it is the difference between these two sub-stages that constitutes the difference between handaxes and $\sqrt{-1}$. The first substage is that of concrete operations and the second that of formal or propositional operations. Concrete operations are used to organise tangible entities, e.g., tools, structures, people, etc., while propositional operations are used to organise ideas and hypothetical entities, e.g., non-commutative rings, infinities, etc. (Piaget 1972). Because artefacts are tangible entities they require at most only concrete operations. Could it not then be argued that the Isimila hominids were incapable of propositional operations and were therefore not as intelligent as modern humans? I believe not.

Because propositional operations are not employed to organise tangible things they could never be recognised with certainty in prehistoric data, even recent prehistoric data. We will never know whether or not *any* prehistoric people used propositional operations. More importantly, however, cross-cultural data suggest that use of propositional operations, in a strictly Piagetian sense, is far from universal among modern humans (Dasen 1977). The basic Piagetian sequence of ontogenetic stages appears to be universal. Operational intelligence *sensu lato* is characteristic of adults but propositional operations are often absent. Indeed, they seem to be a particular kind of operational thinking found among educated adults (Dasen 1977). This appears to be not a difference in competence (both concrete and propositional operations are reversible, conserving, etc.) but a difference in realms of application. Therefore, even if the Isimila hominids did not employ propositional operations (and we can never know) this could not be interpreted as a difference in competence.

There is, of course, a vast difference between the technological achievements of modern humans and later Acheulean hominids. Prehistorians have often attributed modern technological sophistication to an intellectual capacity achieved late in the Upper Pleistocene. As a recent text states: there was '... a change in adaptive strategies and *organizational abilities* at the beginning of the Upper Palaeolithic. This transition signifies the *rapidly increasing ability* of human beings to recognize the environmental potentials that existed [and] to communicate these potentials to others...' (Redman 1978: 51–2) (my emphasis). Redman is clearly citing increased intelligence as a factor in cultural evolution as late as the Upper Palaeolithic. Such reasoning is based either on the assumption that modern intelligence must correlate directly with the appearance of morphologically modern humans or on the assumption that it correlates with the appearance of blade technology.

To assume the former is to assume that intelligence was a factor of importance in later human biological evolution. I believe this assumption is at least open to question. While Neanderthal brains differed in shape from those of modern humans (Kochetkova 1978) the significance of this difference is far from clear. Anatomists are reluctant to infer behaviour from endocasts. 'More, however, must be learned about the functional significance of observed changes in brain size and shape before reliable inferences can be made from endocasts about changing behavioural abilities.... Given the nature of hominid endocasts, I believe that the archaeological record will ultimately allow more inferences about behavior than will endocasts' (Radinsky 1976: 384).

The assumption that blade technology (or parietal art) requires more intelligence than Levallois flakes or handaxes is also open to question. To my knowledge no one has ever rigorously demonstrated that the spatial concepts necessary for blades are more complex than those for earlier tools. I maintain that the spatial concepts necessary to manufacture blades are no more complex than those necessary to manufacture handaxes—indeed they are perhaps less so. Blades require the whole–part operation to produce and monitor the core but do not require the spatio-temporal substitution and symmetry operations of symmetrical handaxes.

The analysis of Isimila artefacts indicates that operational concepts of space were employed by later Acheulean hominids. The organisational abilities referred to by Redman were apparently achieved long before the Upper Palaeolithic. In place of the assumption that intelligence played a part in much of later cultural evolution I offer the alternative hypothesis that cultural developments since the later Acheulean represent just that—cultural developments—and not an increase in intelligence. We must look elsewhere for the leading factors in this development.

Implications for other behaviour

To conclude that later Acheulean hominids employed operational intelligence tells us almost nothing specific about the content of mind, the actual knowledge, of these hominids—whether or not they had a language with formal grammar, or a numbering system or a yearly schedule for resource exploitation. But it does tell us a great deal about the capabilities these hominids possessed for organising physical phenomena. To characterise thought as operational is to recognise a sophisticated degree of cognitive organisation, one with conservation, precorrection of errors, transitivity, etc. That these organisational abilities were recognised in the realm of spatial organisation—infra-logical thought—does not restrict them to this realm. The same organisational principles are involved in all realms of thinking. Here the power of a structural theory is most useful. From a characterisation of organisational principles one can begin to discuss the possible nature of specific forms of behaviour. Inferences can be drawn from three different levels of the analysis: from the infra-logical operations directly, from the parallel logico-mathematical operations, and from the overall stage of development, i.e., operational thought in general.

From the infra-logical structures it is possible to extrapolate other possible space-orientated behaviours of the hominids. Perhaps the most significant such inference concerns Euclidean space.

Euclidean space as we generally think of it consists of a three-dimensional space defined by coordinate axes. It is a space of positions. In a sense, one empties space of objects and organises what is left by means of a reference system, i.e., all of the potential positions objects may hold (Piaget & Inhelder 1967). In everyday life, of course, space is not consciously conceived in terms of axes; nevertheless it is acted upon with the expectation that positions, not just objects, exist. Coordinate axes are merely a formalisation of this conception. Coordinate axes are constructed by the multiplication of an arbitrary series (the axes) through several dimensions. These arbitrary series are constructed by qualitative displacement, i.e., each position or value of the series bears a specific spatial relation to all of the others (e.g., A < B < C or 1 < 2 < 3). When such a series is multiplied through three dimensions it defines a space in which each position has a unique and absolute value. Objects that occupy this space occupy permanent positions and can be related spatially to all other objects because the positions are defined. This kind of space is inferable for Isimila hominids from the geometry of the finer bifaces. As we have seen, the Isimila hominids possessed a competence in operational qualitative displacement, i.e., the ability to create a series. The finer bifaces suggest that the equivalent of three-dimensional reference frames must have been employed. Without a conception of a space of defined positions, it would have been impossible to conceive an object which has bilateral symmetry across three planes. Flake removals were made not in relation to nearby flake removals but according to a set of positions which defined the symmetries. This frame was internal to the artefact but was nevertheless a Euclidean space.

One interesting implication of the above inference concerns the structuring of geographic space and the ability to map. Though it cannot be demonstrated from artefacts, it is reasonable to believe that Euclidean concepts would also have been applied to geography so that landmarks—hills, rivers, etc.—were conceived as occupying positions that held a constant measured relation to one another. If space were not so structured and there were no constant frame of reference, then a landmark approached from a new direction could not have been placed in its proper position and could, from the point of view of the observer, have remained unrecognised. It would not be impossible to function within such a space but learning the geography of an area would be laborious. Landmarks would bear relation to other landmarks but would not occupy fixed positions. Giving directions from one distant location to a second distant location would present difficulties (if the route had not been previously memorised) because these locations would not be conceived as occupying permanent positions related by means of an absolute frame of reference. If geographic space were structured by Euclidean relations then directions could be given from any point in an area to any other by simply constructing a route through a permanent framework of positions for which landmarks are just that—markers. Mapping is slightly different in that it is basically a system of symbolic correspondence dependent on representational ability. Maps are not necessarily Euclidean. A map can, for example, respect only topological relations as do maps of the London Underground. However, when an ability to map is combined with a Euclidean space the result is a useful tool for communicating about geographical surroundings. The prerequisite abilities for this were possessed by the Isimila hominids.

For each of the infra-logical structures there is an equivalent logico-mathematical structure. Unlike infra-logical structures which regulate relations within spaces (geography, objects, etc.), logico-mathematical structures regulate relations between discontinuous phenomena. Logico-mathematical structures are necessary for a great range of human behaviour, most of which is totally invisible archaeologically. However, logico-mathematical operations require the same organisational principles (i.e., reversibility and conservation) as do infra-logical operations and, given a competence in one, it is reasonable to infer a competence in the other.

The logico-mathematical equivalent to whole–part relations is classification (formalised $A + A' = B$). This powerful organisational tool is crucial to much of human behaviour. Kinship systems, for example, are based on classification. Distinguishing cross-cousins from all cousins and affines from consanguines would be impossible without the ability to form classes and classes of classes. True, classification is unnecessary for recognition of simple relations, e.g., mother–offspring, but kinship systems are never so simple and anything more complex requires combining individuals by means of arbitrary and abstract features, i.e., classification. The infra-logical equivalent of classification has been shown to have been employed by the Isimila hominids. It can therefore be concluded that these hominids were at least capable of creating kinship systems as complex as any existing today.

Serial relations are the logico-mathematical equivalent of infra-logical qualitative displacement. The concept of number results from a coordination of serial order and classification (see Piaget 1952). Now, it would be difficult to overemphasise the importance of the ability to number. The major characteristic shared by eight oranges and eight rivers is the number eight. Numbering is in this sense a universal means of classifying. There is, of course, no direct evidence that Isimila hominids were capable of counting. However, they did possess the prerequisite classifying and serialising ability, at any rate the parallel infra-logical structures, and were capable of numbering. Numbers are not, it might be added, propositional entities and can be handled perfectly by concrete operations.

The preceding inferences are drawn from specific infra-logical or logico-mathematical structures and as such are either directly or indirectly supportable from the geometry of artefacts. Implications of a more general nature can be drawn from knowledge of the characteristics of operational intelligence. Although such implications cannot be connected directly to the structures employed in artefact manufacture they are consistent with these structures, i.e., all behaviours characteristic of operational thinking require organisations of equal complexity.

An understanding of causality is dependent on concepts of conservation that are not attained until the level of operational thought (Piaget 1975). To understand cause, one must be able to relate the change in one variable to the change in a second variable. This is a reciprocal relationship that is reversible and conserving. Since the later Acheulean hominids employed reversible operations, the obvious implication is that their understanding of causality was potentially no different from our own. This implication has interesting ramifications. If the hominids did understand causality they would probably have recognised causes for most phenomena. If no cause were discernible it is reasonable that one would have been created. It is only when operational thought, through causality, supplies gaps in understanding that such causal mechanisms as magic and cosmogony (and ultimately science) become necessary. This does not mean that later Acheulean hominids did, in fact, employ magic and creation of myths, only that their operational thought was capable of producing the voids that these fill.

The primary conclusion of this study is not that later Acheulean hominids created complex kinship systems or cosmogonies. It is that these hominids employed operational thought in the manufacture of stone tools. Further inferences can be drawn from this conclusion. Because both objects and geographic space are conceived by means of infra-logical regulations the employment of Euclidean relations in one argues strongly for their employment in the other. Inferences concerning classification and other logico-mathematical structures are indirectly supportable through the documentation of the specific parallel infra-logical structures. The more general inferences concerning such concepts as causality are based on general considerations of operational intelligence. These are the least supportable because they cannot be directly related to the artefactual evidence.

Evolution of operational thought

Given the temporal scope of the Palaeolithic, the later Acheulean as represented at Isimila is a relatively recent manifestation of hominid technology. The sophistication of the spatial concepts employed by these hominids should, therefore, not be surprising. But what of earlier stone tool assemblages? This topic has been presented in detail elsewhere (Wynn 1977) and only a few points will be discussed here. The supporting evidence consists of artefacts from Beds I and II at Olduvai Gorge (various localities). Bed I and lower Bed II date from about 1·8 to 1·6 mya (Hay 1976). The top of Bed II has been estimated by Hay to date to 1·15 mya, giving upper Bed II a duration of 500,000, from 1·6 and 1·15 mya. These compare to a date of about 200,000 or 300,000 for the Isimila artefacts discussed above.

The Oldowan artefacts from Bed I and lower Bed II did not require operational intelligence for their manufacture. The symmetries, regular cross-sections and straight edges of later Acheulean artefacts, all of which required infra-logical operations, are not present. The Oldowan artefacts do present regularities but these regularities do not reflect the reversible regulations of operational thinking; rather, they require only the non-reversible regulations of preoperational intelligence, regulations which are much more limited in their ability to organise. Nonreversible regulations do not '... give rise to necessary conservations' (Piaget 1972: 32). True classification, for example, is impossible because '... the quantification of "all" or "some" is still far from being achieved, for the understanding of $A < B$ involves the reversibility $A = B - A'$ and the conservation of the whole B once the part A is abstracted from complimentary A'' (1972: 33).

The same is true of the infra-logical regulations at the preoperational stage; lacking reversibility they are limited in their ability to organise objects. Analogous to the classification example just quoted are the infra-logical regulations relating whole to parts. There are no Oldowan artefacts for which positioning of retouch has been subordinated to achievement of an overall shape (as was clearly the case with the minimally retouched bifaces from Isimila). The artefact was not conceived as a sum of the relationships between the constituent elements, here the flake removals. In making a chopper, the knapper need not have had a clear picture of an end result towards which he positioned the flake removals. Trial-and-error knapping would have sufficed, i.e., removal of flakes until an acceptable result is recognised even though not precisely anticipated. Trial-and-error is a directed regulation which is not reversible and is characteristic of preoperational thinking (Piaget & Inhelder 1967).

The regulations of qualitative displacement employed in knapping Oldowan artefacts were also preoperational. The simplest instance is the pair—one item positioned in relation to one other. Competence in pairs is necessary for the manufacture of a chopper—one flake removal must be placed in relation to at least one other. It is the removal of flakes in pairs which creates the chopper's sharp edge. Even choppers with ten or eleven flake removals can be made simply by removing each flake in relation to one previous flake. This fairly simple relation is the *minimum* concept needed for choppers. Scrapers are more complex: each flake removal must be placed in relation not just to one other, but to all preceding flake removals (e.g., the fourth flake removal must relate to the first and the second as well as the third). This can be accomplished, minimally, by restricting to a single direction all flake removals succeeding the first. Such a constant direction of movement does not require reversible regulations and can be accomplished by trial-and-error. For qualitative displacement as well as for whole–part relations, the minimal competence needed to manufacture Oldowan artefacts is preoperational.

The infra-logical regulations of spatio-temporal substitution and symmetry were apparently not employed in the manufacture of Oldowan artefacts.

Three other categories of Oldowan artefacts—polyhedrons, spheroids and discoids—deserve some discussion. Polyhedrons are by far the simplest artefacts in Oldowan assemblages. The only spatial concept necessary for their manufacture is that of proximity, the placing of one flake removal in the general vicinity of another. Such regulation is simpler than the pairs necessary for choppers and series necessary for scrapers. Spheroids at first consideration seem more regular. A sphere has radial symmetry through three dimensions, is a Euclidean shape and requires operational regulations. However, spheroids which actually approach a sphere in shape are rare; indeed, at Olduvai they are found only in upper Bed II assemblages. Spheroids from Bed I and lower Bed II do not closely resemble a true sphere. At best they are simply polyhedrons with relatively regular radii, a regularity which is not demonstrably intentional. The appelation 'spheroid' reflects more a bias on the part of the archaeologist than a concept used by the hominids. The same is true of the discoids which, for the Oldowan, are simply choppers which have been retouched all around one circumference. The minimum competence is the same as that for choppers.

It has occasionally been argued that the crudity of Oldowan artefacts reflects the motor control abilities of the hominids (e.g. Jolly & Plog 1979: 224). This could not be the case. Many Oldowan assemblages contain small quartz flakes which have been retouched into scrapers and occasionally even awls. These artefacts require as precise a control of motor abilities as that employed in the later Acheulean, indicating that the crudity of Oldowan artefacts reflects not motor ability but conceptual ability. The Oldowan hominids apparently had not achieved the level of operational thought and therefore did not have the reversible regulations necessary for the manufacture of standard shapes, regular cross-sections, or symmetries. Their competence in infra-logical regulations was preoperational. It is necessary to conclude that their competence in other areas was also preoperational.

The evolution of preoperational regulations into the operational structures demonstrable for the later Acheulean hominids cannot be clearly described from the archaeological evidence. Nevertheless, a few observations can be made from the upper Bed II assemblages at Olduvai. Among the Developed Oldowan B and Lower Acheulean assemblages there are bifaces with intentional bilateral symmetry. This required a competence in symmetry regulations. The only apparent difference between these bifaces and the fine Isimila bifaces lies in the attention to cross-section, the upper Bed II bifaces having no demonstrably regular cross-sections. The upper Bed II hominids apparently did not coordinate distance conservation through several dimensions simultaneously. The spheroids and discoids of upper Bed II assemblages are much more regular in proportion than those of Bed I and lower Bed II and an argument can be made that the hominids were employing some concept of constant radius, which is a Euclidean notion requiring reversibility.[2] There is, then, some evidence for the infra-logical operations of symmetry and qualitative displacement among upper Bed II artefacts. These regulations were not as generally applied as among Isimila artefacts—where there are three-dimensional symmetries—and, furthermore, corroborating evidence from whole–part operations or spatio-temporal substitution is lacking. The case for operations is, therefore, much weaker than that for the Isimila artefacts. Nevertheless, the upper Bed II artefacts did require a spatial competence of a more complex sort than that required for the Bed I and lower Bed II artefacts.

The archaeological record from Bed I at Olduvai to the Acheulean site at Isimila spans one and one half million years. It is clear from the artefacts that an evolution in tool-making abilities did occur, an evolution which reflects increasingly complex infra-logical regulations, from the preoperational regulations of Oldowan choppers and scrapers to the operations necessary to conceive and manufacture the fine Acheulean bifaces. The point at which hominids first employed reversible operations cannot be determined. The Upper Bed II artefacts indicate that it may have been as early as 1·1 million years ago.

The one and one half million years from Bed I to Isimila does not exhaust the record of technological development. It is unlikely that the Oldowan represents the earliest stage in hominid stone tool manufacture. The regulations of qualitative displacement necessary for the manufacture of Oldowan scrapers, though not operational, are still relatively sophisticated and are characteristic of the most advanced forms of preoperational intelligence (Piaget 1972; Wynn 1977). There must be earlier and as yet undiscovered assemblages which require more rudimentary conceptions, e.g., which lack scrapers or even choppers.

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1 (A) $p \supset q$ I
(B) $p \cdot \bar{q}$ N
(C) $\bar{p} \supset \bar{q} = q \supset p$ R
(D) $\bar{p} \cdot q$ C
$NR = C : CR = N$; $CN = R$ and $NRC = I$

(Piaget 1972:48)

2 A constant radius is an arbitrary frame in the same sense as is the axis of a grid, and, for the same reasons, requires reversible regulations.

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