

Culture in Bonobos? Between-Species and Within-Species Variation in Behavior¹

GOTTFRIED HOHMANN AND BARBARA FRUTH
*Max-Planck-Institut für Evolutionäre Anthropologie,
Leipzig, Germany (hohmann@eva.mpg.de)/Max-
Planck-Institut für Verhaltensphysiologie, Seewiesen,
Germany. 19 III 03*

Long-term studies on wild chimpanzees (*Pan troglodytes*) conducted over the past four decades have revealed extensive behavioral variation within and between local populations (McGrew 1983, Nishida et al. 1983, McGrew 1992, Boesch et al. 1994, Wrangham, de Waal, and McGrew 1994, McGrew et al. 1997, Whiten et al. 1999, McGrew et al. 2001). Because chimpanzees live in different habitats across the African continent, they have to cope with a variety of environmental conditions, and therefore the extent of behavioral variation among them is not unexpected. In response to seasonal drought, populations in West and Central Africa have developed special techniques for obtaining water (Hunt and McGrew 2002, Lanjouw 2002). Chimpanzees in dry habitats with low tree density are reported to use nests repeatedly while those living in dense forest habitats rarely use the same nest twice (Fruth and Hohmann 1996). Similarly, the frequency of combining several small trees to construct a single nest varies between populations, probably as a function of forest structure (Fruth and Hohmann 1994). Variation in the extent and quality of insectivory across populations often reflects differences in the availability of prey species (McGrew 1992). Chimpanzees at different sites use different strategies to hunt red colobus monkeys (*Colobus badius*), and some of this variation can be related to the behavior of the prey species, density of forest cover, and, perhaps, food competition between predator and prey (Boesch 1994, Stanford 1998).

While these examples show a correspondence with certain environmental features, others do not. For example, some but not all West African populations of chimpanzees use hammers and anvils to crack hard-shelled nuts (Boesch and Boesch 1983). Because some of the environmental features that are relevant to this behavior (e.g., presence/absence of nuts/tools) seem to be similar across sites, Boesch et al. (1994) have proposed that the differences are likely to reflect cultural traits (see also McGrew et al. 1997). Chimpanzees across Africa spend much time grooming each other, but they do so in various ways (McGrew et al. 2001). In some populations, socially grooming chimpanzees may stretch out their arms and clasp hands. The occurrence of the grooming hand clasp varies between sites (McGrew and Tutin 1978) and sometimes between neighboring communities (McGrew et al. 2001). M-group chimpanzees at Mahale show a grooming pattern that has never been seen elsewhere (Nakamura et al. 2000). Some site-specific grooming patterns may serve no other purpose than to manifest local customs, cases of social conformity in mannerisms. If such behavioral patterns are acquired by social learning and become customary within a local population, they are often labeled "local traditions" or "cultures."

"Culture" is defined in many different ways, and the use of the term for nonhuman animals is the subject of ongoing debate (Galef 1976, McGrew 1992, Tomasello, Kruger, and Ratner 1993, Boesch and Tomasello 1998). The term has been applied to variants of behavior that are socially modified and that elicit corresponding behaviors in others (e.g., Kummer 1971). To distinguish cultures from other types of behavioral variation, three conditions have to be met: (1) acquisition by social learning, (2) sharing of a genotype, and (3) consistency of the relevant ecological factors.

Given the complexity of the ecological systems that are inhabited by *Pan*, it is difficult to assess the degree of similarity of environmental conditions. Moreover, while earlier studies on the genotype of chimpanzees suggested consistent differences between subspecies (Morin et al. 1994), recent work in molecular taxonomy has complicated our understanding of chimpanzee systematics (Gagneux et al. 2001). Thus, assessment of the nature of geographic variation in behavior depends largely on the mode of acquisition and transmission. However, as the process of acquisition is more often inferred than observed (King 1994), the term is usually a label for behavioral variation between populations, that is, patterns that are present in one but absent in another or that exist in different versions (McGrew 1998). The criterion of geographic variation is still debated because ecological differences between sites may create divergence between populations through individual learning (Tomasello 1999). When variation is of the presence-ab-

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sence type, the cultural trait is usually associated with the population that shows the given behavior. While this distinction seems plausible, it overlooks the fact that the same process that leads to the appearance of a given pattern may also lead to its avoidance. For example, in forests where hunting pressure is high, primates (and probably other mammals) change their vocal activity and their behavioral response to the calls of potential predators (van Schaik 1983, Bshary 2001).

One operational approach is to *infer* that a behavioral pattern represents culture when it is considered as such in a closely related species. The advantage of this approach is that attention is drawn to a behavior or the variation of a behavioral pattern that would otherwise remain unnoticed. The disadvantage is that patterns that are either unknown or absent in the other species will be missed.

Reports on cultural variation in primates date back to work by Hayes and Hayes (1952), Yamada (1957), Goodall (1964), Kawai (1965) and Kummer (1971). Recent attempts to assess the dimensions and extent of behavioral variation that might reflect cultural traits rather than genetically determined or individually learned patterns have focused on chimpanzees (Whiten et al. 1999, 2002). Following a suggestion of McGrew (1992) that drawing comparisons between the two *Pan* species could be a good starting point to discover bonobo culture, in this study we compare the behavior of bonobos from Lomako with the most recent and most comprehensive account of cultures in chimpanzees. Various studies have compared the behavioral repertoires of the two *Pan* species (de Waal 1988, Takahata, Ihobe, and Idani 1996, Nishida et al. 1999), but bonobos are usually not considered in reports on chimpanzee cultures. Since long-term observations of habituated bonobos are restricted to two sites, the potential for evaluating intraspecific variation is limited. Instead of comparing the behavioral repertoires of these two populations, this study explores between-species variation and overlap, assuming that similar behavioral patterns may originate in similar ways. Using published information from other sites, the variation of these patterns across different bonobo populations is discussed.

METHODS

Behavioral observations of bonobos at Lomako were made between 1991 and 1998. The eight field seasons at Lomako ranged from 2 to 9 months (total time of field observation: 48 months). The study involved members of the Eyengo community inhabiting the eastern part of the Lomako study site (Badrian and Badrian 1984). Over the years, the size of the community ranged from 15 to 24 mature individuals, with the number of adult females always exceeding the number of adult males (Hohmann and Fruth 2002). We did not focus on the ontogeny of behavioral patterns, and therefore information on their development is absent or, at best, fragmentary. In this study the term "culture" refers to behavioral patterns shown by Lomako bonobos that correspond with can-

didates for chimpanzee culture as described by Whiten et al. (1999) and to behaviors that appear to vary between bonobo populations without corresponding environmental differences. The latter category includes both population-specific versions of the same pattern and patterns that are present at Lomako but absent at other sites.

Records were made by all-occurrence sampling (Altman 1974). Assignments of codes for the frequency of occurrence of different behaviors followed the conventions used by Whiten et al. (1999): Patterns are *customary* (C) if they occur in all or most members of at least one age-sex class. Patterns are *habitual* (H) if they have been seen repeatedly in several individuals. Patterns are *present* (P) if they are clearly identified but neither habitual nor customary.

Information from other bonobo populations and from chimpanzees was taken from published reports. Identification of candidates for a cultural pattern among Lomako bonobos was made whenever we noted a behavior that was not mentioned in the literature available to us. The major sources for intraspecific comparison are the reports by Kano (1992), Ingmanson (1996), and Nishida et al. (1999). Takeshi Furuichi kindly provided unpublished information on some behavioral patterns. The locations of the field sites mentioned in the text are shown in figure 1. For interspecific comparison we used an ethogram compiled by the contributors to the publications of Whiten et al. (1999, 2002).

RESULTS

Of 65 behavioral patterns that are listed as candidates for cultural behavior in chimpanzees by Whiten et al. (1999), 14 have equivalents in bonobos from Lomako (table 1). These patterns may be described as follows:

Branch drag. In branch dragging, the individual usually stands bipedal by a small tree, grasps the trunk with one hand, bends the upper part away from the body with the other hand, and breaks it by pulling the first hand to-

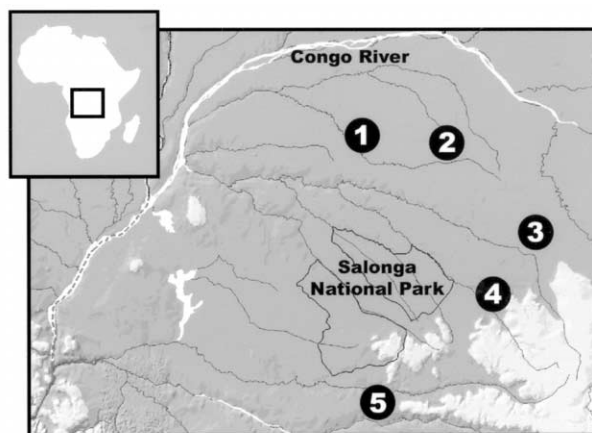


FIG. 1. Locations of field sites. 1, Lomako; 2, Wamba; 3, Yalosidi; 4, Lilungu; 5, Lukuru.

TABLE 1

Candidates for Cultural Behavior in Chimpanzees (Whiten et al. 1999) Observed in Lomako Bonobos

Distribution in Chimpanzees ^a	Behavioral Pattern	Code Number	Sex of Performer ^c	Frequency of Occurrence ^d
A	Branch drag	3	F, M	C
A	Branch clasp	5	F, M	C
A	Branch shake	6	F, M	C
A	Buttress beat	7	M	C
D	Branch slap	62	M	C
D	Leaf clip by mouth	53	F	H
D	Leaf clip by fingers	54	F, M	H
D	Leaf strip	55	M	H
D	Hand clasp	59	F, M	H
A ^b	Leaf sponge	4	F	P
D	Vegetation seat	46	F, M	P
D	Fly whisk	47	F, M	P
D	Aimed throw	49	M	P
D	Branch din	61	M	P

^aA, chimp universal; D, cultural trait.^bChimpanzees and bonobos use different materials.^cM, male; F, female.^dC, customary; H, habitual; P, present.

wards the body. With the broken end held in one hand, the crown is then dragged along the ground. Sometimes vines are used instead of trees. Branch dragging occurs daily and within a day may be seen many times. In one case, branches were dragged 21 times within an hour. The pattern is displayed most often by mature males (89% of 493 performances when the sex of the individual was known) and less often by older juvenile males (7%) or by adult females (4%).

Leaf sponge. The use of “sponges” was seen four times when juvenile and adolescent females dipped water from a tree hole. In Lomako, bonobos have access to surface water year-round, and three of the four observations took place during the wet season. In contrast to most chimpanzees, bonobos use mosses collected from nearby trees for this purpose.

Branch clasp. When bonobos are grooming each other in trees, one or both individuals commonly hold onto branches. Although this pattern was not systematically recorded, it is a common element of most grooming episodes. While branch clasping by chimpanzees seems to be stereotypic (one arm is stretched out to grasp a branch overhead), bonobos also hold onto branches that are behind them or to the side.

Branch shake. Mature males and immatures of both sexes shake branches noisily during agonistic displays directed at humans, monkeys, or conspecifics. The pattern occurred during all the community encounters that were observed ($N = 23$) (Hohmann and Fruth 2002). Males and females also shake branches when soliciting mating. In this context, branch shaking was observed nine times for males and three times for females and was accompanied by gazing at the partner, penile display (in males), waving the arm in the partner’s direction, and/or clipping leaves.

Buttress beat. Bonobos run up buttress roots of large

trees and slap/stamp on them with their hands and feet. Of 384 observation days, drumming was heard at least once on 85. Drumming is often correlated with long-distance vocalizations (high hoot, low hoot). All the observed buttress beats involved mature males.

Vegetation seat. Male and female bonobos sometimes bend small trees or shrubs to the ground and sit down on their leafy parts. Performance of this behavior was seen at least five times. Four times we found abandoned resting sites where vegetation had apparently been used as a cushion. In contrast to the chimpanzees at Bossou (Hirata, Myowa, and Matsuzawa 1998), the Lomako bonobos do not sit on single, detached leaves.

Fly whisk. In the dry season, females sometimes use small, leafy twigs to shoo away sweat bees from their genital swellings. The same pattern was seen when a male tried to wave bees away from his wounded hand.

Aimed throw. Juveniles and adults of both sexes throw sticks and branches at human observers and at other bonobos. Twigs and branches were aimed at human observers 13 times. Juveniles twice threw unripe fruits (*Irvingia* sp.) at a tortoise.

Leaf clip by mouth. Immatures of both sexes and mature females clip leaves from herbs or trees and hold them in their lips (and perhaps teeth) while looking at another individual. The pattern occurred during 25 of the 61 episodes of social play recorded and was interpreted as an attempt to solicit social play.

Leaf clip by hand. The ripping of leaves from ground vegetation or from trees was noticed 11 times and was interpreted as an attempt to get the attention of a mating partner. Overall, the pattern appears the same as handling leaves in the context of foraging except that the leaves are not consumed. Only mature females have been seen to use the pattern to attract males.

Leaf strip. During play or mild agonistic display, ma-

ture and immature individuals of both sexes tear leaves from saplings or branches. Five times the behavior was related to encounters with members of another community. It was not always clear if the leaf stripping was intended or resulted from a failed attempt to uproot a small tree or to break off branches.

Hand clasp. Individuals being groomed may lift an arm, probably to give better access to the groomer. Similarly, groomers may lift a groomee's arm and hold the arm in this position by clasping the hand of the groomee. Like the branch clasp, this pattern is a common element of most grooming episodes. In chimpanzees two individuals clasp hands overhead, grooming each other with the other hand (McGrew and Tutin 1978). Hand clasping by Lomako bonobos differs in that (1) the two individuals do not simultaneously groom, (2) the hand clasp results from the action of only one individual, and (3) the hand clasp does not appear to be ritualized.

Branch din. When traveling on the ground, male bonobos often bend saplings or shrubs and then release them. This makes a sudden noise and may inform others of the actors' location. The same pattern occurs when males of different communities direct displays at each other. A similar pattern is shown when bonobos bend smaller trees in order to descend to the ground (tree elevator) and, after descending, sit and hold onto the tree before releasing it later. During community encounters the pattern was recorded 72 times. Whether this pattern serves to warn others (see Whiten et al. 1999: table 1) is not clear, and at least in the context of an intercommunity encounter it seems unlikely to do so. The circumstances in which this behavior occurred suggest that it may be an alternative to vocalization.

Branch slap. While sitting in a tree, males and females slap noisily on either the branch supporting them or the tree's trunk. This pattern is part of short-distance communication and may be a mild agonistic display directed at conspecifics or humans. It was seen at least once during all the community encounters recorded.

In addition to the behavioral patterns that seem to be common to the two *Pan* species, bonobos at Lomako perform patterns that are rare or absent in chimpanzees (table 2). Patterns were included in this list on two criteria: (1) overall resemblance to patterns of chimpanzees that are assumed to be transmitted by social learning or imitation and (2) preliminary evidence for variation between bonobo populations. These patterns may be described as follows:

Duiker chase. Bonobos of both sexes occasionally lunge at a duiker (*Cephalophus* sp.), but only females are seen to inspect hollows and spaces between large buttress roots where duikers are likely to rest during the day. Twice a female was seen to catch a hidden duiker. When duikers are caught by bonobos ($N = 9$ cases), the prey is divided among mature party members.

Food rub. When eating fruit found on the ground (e.g., *Irvingia*, *Aurantella*, *Gambeya*), an individual may take a fruit, hold it in the palm of one hand, and wipe the surface with the palm (or occasionally the back) of the other hand. This treatment seems to clean the surface

TABLE 2

Candidates for Cultural Behavior Observed in Lomako Bonobos But Rare or Absent in Chimpanzees

Behavioral Pattern	Sex of Performer ^a	Frequency ^b
Duiker chase	F, M	C
Food rub	F, M	C
Forage wade	F, M	C
Groom slap	M	H
Upside-down hanging	F	H
Leaf cover	F, M	H
Food detachment	F	P
with feet		
Stick scratch	F	P
Teeth chatter	F	P

^aM, male; F, female.

^bC, customary; H, habitual; P, present.

of fruits chosen as food. Mature and immature males and females show this pattern.

Groom slap. A groomer may suddenly strike the groomee with a flat palm, making a sound that is audible to human observers up to about 20 m away. Groom-slapping individuals seem to be more agitated and aroused than silent groomers. Groomers direct blows at various body parts (limbs, chest back) but never at the head or face of the groomee. Groom slapping is done by mature and juvenile males and directed at adults of both sexes. Sometimes a slap coincides with a change of grooming position.

Upside-down hanging. An individual hangs bottom-up with hands grasping a branch and the legs, abducted at the hip, either slightly bent around the branch or hanging free with the knees touching the chest. Females may press their genitals against the supporting branch. Occasionally the head-shake and the open-mouth grin accompany this suspension, which may last for several minutes. The behavior is shown by mature females only and always occurs early in the morning before bonobos leave the nest site. Five of the 14 resident females showed this behavior. It may be that females masturbate while hanging upside-down, but the function remains ambiguous.

Leaf cover. Having constructed an overnight nest, the bonobo covers the ventrum of its body with several leafy twigs. The leaf-cover pattern is common during the rainy season and seems to serve as temperature regulation.

Fruit detachment with feet. Whereas bonobos usually remove fruit from twigs and branches by picking them with either the lips or the fingers, one female was seen to use a different technique to remove large fruits of *Treculia africana*. Holding fast to a branch, she stepped on the fruit and pushed with her feet until the fruit became detached and dropped. On two other occasions, three other females tried to detach fruit in this way but failed.

Stick scratch. An adult female was once observed to break off a twig from a tree and use it to scratch her back. On another occasion, a juvenile female carried an old

stick from the ground into the tree and scratched her wrists and back with it.

Teeth chatter. The teeth chatter is created by rapidly grinding together the upper and lower teeth rows, and three adult females showed this pattern during genital contacts with other females. At other times females had genital contacts *without* producing this sound.

Forage wade. During the dry season, males and females of all ages walk quadrupedally along streambeds for up to an hour, stopping now and then to search through the matrix of rotten leaves and soil for insect larvae and small *Crustacea*. The depth of these streams averages about 20 cm, and where deeper pools occur the bonobos cross them by climbing into trees.

DISCUSSION

Between-species comparison. The comparison of patterns performed by chimpanzees and bonobos, respectively, shows much overlap. Interestingly, the similarities include both chimpanzee universals and patterns that are present in some but not all chimpanzee populations. The latter group is of special interest because the presence of a given pattern in populations of both species conflicts with two criteria that are often used to define culture: common gene pool and transmission through social learning. There are several possible explanations for this phenomenon. First, the patterns in question may be *Pan* universals that have escaped the attention of human observers at some sites or, alternatively, have been lost in some places. Secondly, the patterns may have evolved independently in the two *Pan* species. Third, the patterns may have been transmitted from one species to the other by imitation. Though more research is needed to permit a more definitive weighting of these alternative hypotheses, we consider the third explanation unlikely under the current conditions of allopatry. Following the principle of parsimony, we prefer the first explanation. In their account of local traditions in orangutans (*Pongo pygmaeus*), van Schaik et al. (2003) found discontinuity in the distribution of certain behavioral patterns across populations and proposed that behaviors acquired by social learning may get lost when local populations become isolated.

Table 1 shows the overlap to be biased towards communication: material cultural patterns that are common in some populations of chimpanzees are underrepresented in bonobos. In captivity, bonobos learn to use probes to extract food from containers and make flaked stone tools to cut other materials (Toth et al. 1993). Experimental studies indicate no differences in the cognitive capacities of the two members of the genus *Pan* (Inoue-Nakamura 1997, Hyatt and Hopkins 1998). Therefore this discrepancy in the use of tools and technologies under natural conditions requires explanation.

There are two major context categories for tool use by chimpanzees: opening hard-shelled fruits and extracting insects (McGrew 1992). Do bonobos show the same behavior as chimpanzees, and if so, how do they perform these tasks? First, Lomako has several tree species with hard-shelled fruits that chimpanzees open with the help

of tools (*Panda oleosa*, *Parinari excelsa*). During fruiting season, the exocarp of *Parinari* is a major component of the diet, but there is no evidence that bonobos try to open the hard seeds of this fruit. There is no evidence that *Panda oleosa* is eaten by Lomako bonobos. However, stones are very rare and appear to be too soft to serve as potential tools. Thus, it may be that the absence of suitable tools prevents bonobos from cracking nuts. Second, faecal analyses and direct observations show insectivory in bonobos (Badrian and Malenky 1984, Kano 1992, Sabater-Pi and Veá 1994, our observations), but no systematic study has been made of the abundance, distribution, or density of potential insect prey or of their significance in the diet of bonobos. Therefore, we cannot rule out the possibility that some of the differences in tool use reflect the distribution of suitable prey species. An alternative explanation is that bonobos may have access to other food sources (e.g., plant foods) that make such time-consuming activities as termite fishing superfluous (McGrew et al. 1997). According to Whiten et al. (1999), tool use varies across populations of chimpanzees and ecological explanations account for some but not all of this variation. Thus, neither the patterning of presence or absence of nut cracking nor the distribution of tool use for obtaining insects produces clusters that separate the two *Pan* species from each other. Although the use of tools by bonobos appears to be at the lower end of the range for chimpanzees, it resembles what is known from some Ugandan populations of *Pan troglodytes* (e.g., Kibale, Budongo). Comparison of the feeding ecology of bonobos with that of chimpanzees that are poor tool users versus skilled tool users may illuminate the evolution of material culture in *Pan*.

Various studies have searched for variables that might explain intra- and interspecific differences in tool use. Boesch (1996) explored whether the number of different types of tool use within a given population varied with the degree of gregariousness (measured as average party size) but found no support for this hypothesis. Van Schaik, Deaner, and Merrill (1999) have proposed a number of conditions that promote the evolution of tool use: extractive foraging, manual dexterity, intelligence, and social tolerance. While the model explains some differences in tool use by Bornean versus Sumatran orangutans (*Pongo pygmaeus*) and between different chimpanzee populations, the differences between the two *Pan* species do not follow its predictions. Using the same measures for social tolerance that were used to rank different populations of chimpanzees, Lomako bonobos would probably end up with an intermediate rank; solitary individuals are rare (Hohmann and Fruth 2002) and food sharing is frequent (Fruth and Hohmann 2002). However, interbirth intervals are relatively long (our data), cooperative hunting is rare or absent (Fruth and Hohmann 2002), and grooming is most often between males and females (Hohmann et al. 1999).

One element that may be crucial in understanding differences in tool use was not tested in the model presented by van Schaik, Deaner, and Merrill (1999): variation in extractive foraging. Comparing the morphology of fruits

at sites with tool use versus sites where tool use is absent could test this hypothesis. Another way to investigate differences in tool use across populations and species is to quantify the advantages that derive from tool use. Although exceptions are known to exist (Yamakoshi and Sugiyama 1995), inventions that provide large fitness gains will be adopted while others disappear. Intuitively, one would predict that tool use that helps to extract food that is otherwise inaccessible spreads quickly from the inventor to others. Woodpecker finches (*Cactospiza pallida*) from Santa Cruz Island in the Galapagos differ in their use of tools to extract hidden insects. One population, living in an area where food is abundant and easily accessible, does not use tools. Another population, living in an arid zone where food is limited and access to it is constrained, uses tools and does so more often in the dry season than in the wet season. Experiments with naïve birds show that individuals from both populations use tools to extract embedded food (Tebich et al. 2001). Tebich et al. (n.d.) proposed that in this avian tool-using species the development of tool use results from the variation in the availability of food that is caused by irregular changes in climate. Seasonal changes in the frequency of tool use in birds from the dry habitat and the absence of tool use in birds from the rich environment suggest that the benefits that derive from tool-enhanced foraging do not always exceed its costs. Thus, it seems likely that in this case tool use is enforced by environmental constraints.

Comparing the complexity of cultural patterns and local traditions shown by chimpanzees and orangutans with that shown by bonobos, the bonobos appear inferior. The most likely explanation is that this difference reflects our limited knowledge of wild bonobos. Long-term studies are restricted to two populations, and the number of individuals observed at each site is relatively small. There are alternative ways of explaining limited cultural variation. In orangutans hunting and/or the loss, degradation, and fragmentation of habitat are thought to be responsible for the absence of certain patterns of tool use (van Schaik et al. 2003). The data to test this hypothesis for bonobos are not yet available, but information on intercommunity relations within local populations does not support it (Idani 1991, Hohmann and Fruth 2002). Thus, the discrepancy in the complexity of culture between bonobos and other great apes remains ambiguous.

Within-species comparison. Comparison of the behavior of Lomako bonobos with reports from other sites indicates both similarities and differences between populations, for example, in the hunting of mammalian prey. Considering the long duration of fieldwork at Wamba, the complete lack of evidence for the hunting or eating of duikers is compelling. At Lomako, duikers are rarely hunted, and the meat is always divided among mature community members (Fruth and Hohmann 2002). At our new study site in the southern sector of Salonga National Park, duiker hair was found in fresh faeces. Duikers occur at both sites, and at Wamba bonobos eat the meat of small mammals (Ihobe 1992). At Lilungu, bonobos catch guenons (*Cercopithecus ascanius*) and black-and-

white colobus monkeys (*Colobus angolensis*), but no eating of the prey has been seen. Instead, the bonobos seemed to catch the monkeys for playthings (Sabater Pi et al. 1993). Chimpanzees also sometimes catch and kill red colobus, their most important prey species, but occasionally do not eat the victim (Boesch, Uehara, and Ihobe 2002). It is apparent that to conclude that bonobos do not hunt other primates for meat would be premature.

Differences in hunting strategies, hunting techniques, and prey image are not included in the accounts on cultural differentiation published by Whiten et al. (1999, 2002), much of the observed variation being attributed to differences in habitat structure, demography of the prey species, and feeding competition (Boesch, Uehara, and Ihobe 2002). However, detailed studies on interpopulation variation of hunting behavior are restricted to one prey species, red colobus, and the nature of many differences remains to be explained (McGrew 1998). One is the hunting of duiker, the pattern that appears to differentiate the bonobos of Lomako and Wamba. Others are differences in habits of consumption of prey (Boesch and Boesch 1989).

Previous studies have revealed much overlap in the behavioral repertoires of bonobos from different sites (e.g., Nishida et al. 1999): Branch dragging has been reported from Lomako (Badrian and Badrian 1984) and Wamba (Ingmanson 1996). At all sites, the pattern occurs in departure as well as in agonistic display. Because it coincides with the departure from one place, it is most often done early in the morning when a party leaves its nest site and after long feeding bouts in large food patches. Another context for this behavior is encounters between members of different communities. Branch dragging displays combine several elements including manual manipulation (breaking off branches or small trees), locomotion (running), and sound production (vocal and nonvocal). Considering this complexity, the potential for variation within and between populations is high and remains to be explored. Other behavioral patterns such as buttress drumming occur also at Wamba but seem to vary in performance. According to Ingmanson (1996), bonobos at Wamba drum with their feet, while at Lomako drumming is done with hands alone or with hands and feet. At both sites mutual grooming is a daily behavior but the mode of performance differs: At Wamba simultaneous grooming is common (Takeshi Furuichi, personal communication), while at Lomako grooming is usually alternating or unidirectional (Hohmann et al. 1999).

Several types of tool use described for bonobos at Wamba by Ingmanson (1996) have not been seen at Lomako. This includes the use of leaves as a rain hat, a toothpick, or a napkin. Several community members frequently use rain hats. Bonobos at Lomako show a different pattern that may serve a similar purpose: During the rainy season, bonobos cover their bodies with twigs and leaves when using a night nest (Fruth 1995). Wamba and Lomako have similar ranges of rainfall and similar temperature (Fruth 1995, Furuichi et al. 1998), and neither form of leaf cover requires special raw material. Therefore it seems unlikely that the differences in tool

use between Lomako and Wamba reflect environmental differences between the two sites.

Foraging in streams and pools has been reported from Yalosidi (Uehara 1988), Wamba (Kano 1992), Lukuru (Myers-Thompson 2002), and Lomako (Fruth 1995). Variation seems to exist in the type of locomotion that occurs in this context: While bonobos at Lomako remain quadrupedal when wading, reports from Wamba and from Lukuru indicate that bonobos often go bipedal. This difference may well reflect differences in habitat or in activity (fishing for insects versus fishing for algae), flexible patterns of foraging that are likely to involve social learning.

In sum, current evidence suggests behavioral variation across bonobo populations: (1) Lomako and Wamba bonobos show patterns that are absent in the other population. (2) Other patterns seen in both populations show subtle differences in performance (e.g., rain cover, buttress drum). Given the relatively close proximity (182 km) of Wamba and Lomako, the absence of major geographic barriers to dispersal (e.g., wide rivers, plantations, roads), and the similarity in climate, these behavioral differences are considered candidates for cultural traits. This situation parallels that of Gombe and Mahale (Nishida et al. 1983).

In addition to the small number of bonobo groups that have been studied, there is another limitation. To date, information comes almost exclusively from Wamba and Lomako, two sites in the northern part of the species's range of distribution. Until recently, bonobos were thought to be restricted to areas of the Congo basin that are covered by primary lowland forest. Recent studies show that the species occurs in a wider range of habitats (Myers-Thompson 2002, Hohmann and Eriksson 1999, 2000). With more field research on bonobos, other populations living in areas that are not yet included in the range of distribution are likely to be found. Greater seasonal changes in climate, broken forest cover, and varying floristic composition of habitats are likely to promote behavioral strategies that are uncommon or absent in Lomako and Wamba. Some prospects are of particular interest. First, the reduction in forest cover and the increase in grassland in the southern part of the bonobos' species distribution provides access to social insects that may not be available in dense forest areas such as Lomako and Wamba. Studies of these populations will show whether bonobos make use of such food sources and whether they use tools to do so. Second, if seasonal differences in food availability increase, bonobos may benefit from using more complex techniques of food processing and food collection.

Our report on behavioral variation of bonobos from Lomako is preliminary, and more patterns may be discovered while others may turn out to be universals. The ethogram of Mahale chimpanzees published by Nishida et al. (1999) also makes reference to bonobos and provides hints of more extensive within-species differences. The discovery that bonobos perform a number of behavioral patterns that are classed as cultural traits in some chimpanzee populations raises a number of interesting questions that are a challenge for future research. How similar/different are

these patterns in form and function? Does the resemblance of bonobos and some East African chimpanzee populations reflect ecological similarities? Do differences in the gregariousness of males versus females affect the spatial diffusion of cultural behaviors? This report is not the final word on cultural patterns in Lomako bonobos, but we hope that it will stimulate further work.

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Preserving Cultural Traditions in a Period of Instability: The Late Natufian of the Hilly Mediterranean Zone¹

LEORE GROSMAN

*Institute of Archaeology, Hebrew University,
Jerusalem 91905, Israel (lgrosman@h2.hum.huji.ac.il).*
21103

The Near East and in particular the Levantine Corridor (fig. 1) have been a focus of research into the origins of food production since the 19th century. Indeed, in recent decades this region has provided archaeological evidence for the transition from hunting and gathering to village farming. Research on the origins of agriculture is concerned with the description and interpretation of the data

and with issues related to the evolution of the human social structures that led to the flourishing of Neolithic society.

About 2,500 years before the establishment of Neolithic villages, changes were observed in the nomadic human societies of the Levantine Mediterranean zone. The archaeological entity associated with these changes is the Natufian culture, which has been recognized as the harbinger of the food-producing cultures of the Levant (Garrod 1932). Since the 1930s many Natufian sites have been excavated in the Mediterranean region, the Jordan Valley, the Negev, and the Transjordanian Plateau (Bar-Yosef 1991; Edwards 1991; Byrd 1989; Goring-Morris 1987, 1997; Henry 1976; Olszewski and Hill 1997; Valla et al. 1999). Apart from the lithic component, which was the main criterion for its definition, other material remains unique to the Natufian have been recovered, mostly in the Mediterranean geographic zone. Consequently, the Mediterranean zone is commonly referred to as the Natufian "core area," "homeland" (Bar-Yosef and Belfer-Cohen 1992), or "center" (Valla 1995).

A major change in subsistence took place during the early phases of the Natufian culture. There is a growing body of evidence (though mostly circumstantial) that the Natufians were sedentary (Tchernov 1991), and in the Natufian core area there is, for the first time, a distinct development of stone architecture (Bar-Yosef 1991, Valla 1995). A change in the spiritual outlook of the Natufians is also evident from the organization of burials on site, unknown in previous cultures. Additionally, the relative frequency of artistic activities has attracted much attention (Belfer-Cohen 1991), mobile art and decorative elements being rare in the preserved materials of the prehistoric Levant prior to the Natufian. A significant representation of exotic materials (obsidian, malachite, seashells, etc.) indicates contacts with distant regions such as Anatolia (the origin of obsidian) and northern Syria (ochre and basalt) (Valla 1995, Zackheim 1997, Weinstein-Evron, Lang, and Ilani 1999). Not all sites have yielded artistic and symbolic components: there is in fact an association between the larger sites and the presence of burials, structures, ornaments, decorated implements, etc. Thus it seems that it was in these large sites of longer duration that most of the ritual activities pertaining to the dead and their burial took place.

The Natufian has been chronologically subdivided into early (ca. 12,500–11,000 B.P.) and late (ca. 11,000–10,200 B.P. uncalibrated) phases based mostly on changes in certain lithic attributes. A further subdivision adding a final phase (ca. 10,500–10,200 B.P.) was proposed by Valla (1984) on the basis of his excavations at Mallaha (Eynan), the largest known open-air Natufian site, where the most complete stratified sequence of this entity has been found. The changes in this final phase were a shift in the type of retouch employed in shaping lunates and a reduction in their size. Longer lunates with Helwan (bifacial) retouch were gradually replaced by shorter ones modified by an abrupt retouch (Bar-Yosef and Valla 1979, Valla 1984). Natufian flint knapping followed the microlithic tradition established during the preceding cul-

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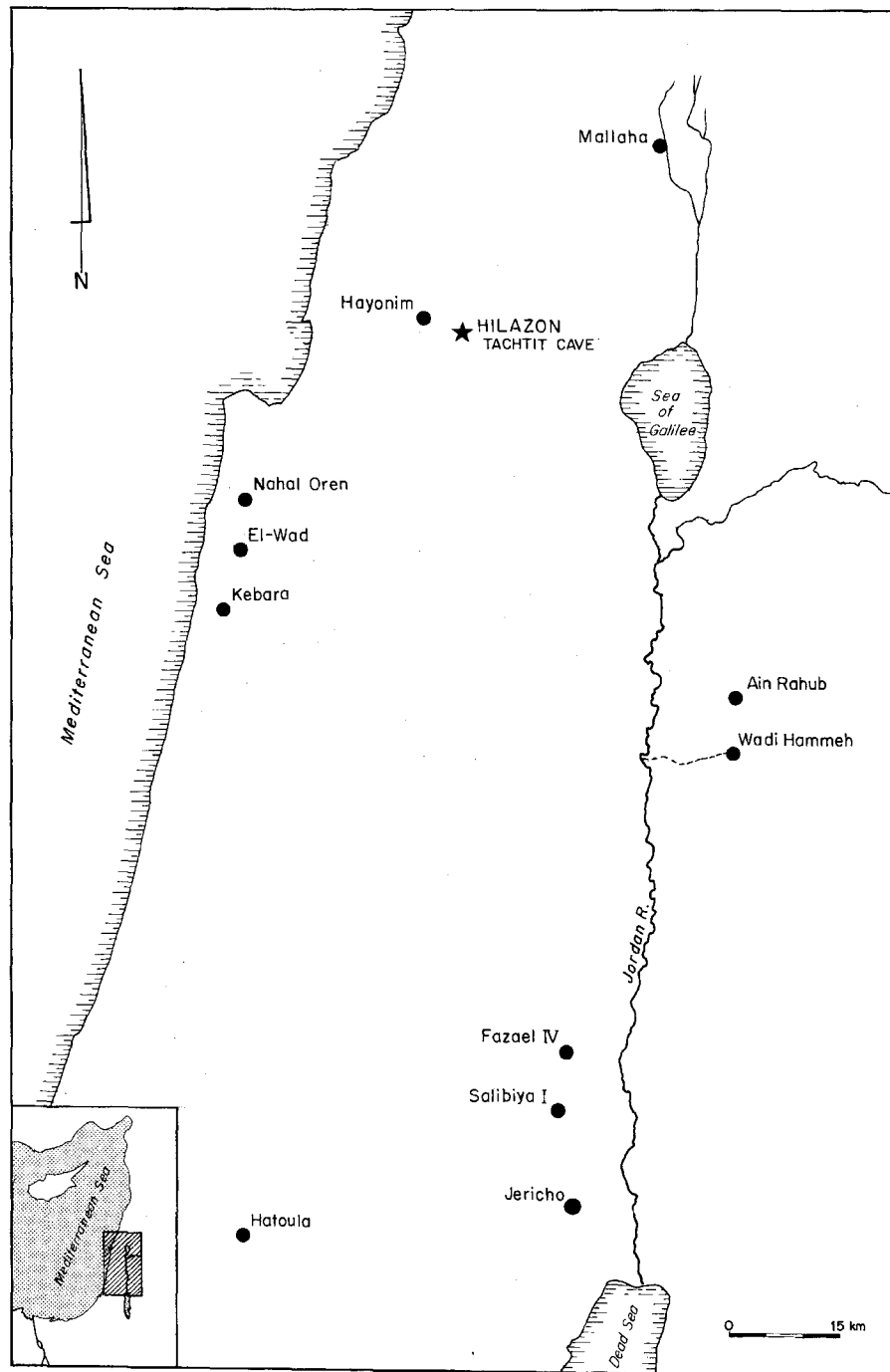


FIG. 1. Part of the Levantine Corridor, showing the location of Hilazon Tachtit Cave and other sites mentioned in the text.

tures coupled with the introduction of new tool types such as the sickle blade (only isolated specimens of which had been recovered earlier).

Most of the characteristic features of the Natufian, which evolved rather quickly in a relative small core area, were recognized in the early Natufian sites. How-

ever, after ca. 1,500 years of Natufian sedentary existence there is evidence for a major shift in settlement pattern and a change in the distribution and density of occupation of sites. A general increase in mobility was expressed in short-term occupations by small bands of hunter-gatherers. Late Natufian sites such as those in

the Lower Jordan Valley were most likely task-specific camps that retained many of the attributes seen in the early Natufian sites of the core area, including a variety of ground stone utensils, bone tools, and artistic manifestations (Grosman, Belfer-Cohen, and Bar-Yosef 1999, Crabtree et al. 1991). At one of these sites, Fazael IV (Grosman, Belfer-Cohen, and Bar-Yosef 1999), the high percentage of sickle blades may indicate the intensification of cereal exploitation. The site was occupied repeatedly and may represent a palimpsest of recurring short-term occupations over an extended time period (Belfer-Cohen and Grosman 1997, Grosman, Belfer-Cohen, and Bar-Yosef 1999). The same can be said for the late Natufian site at Hatula, on the western margin of the Judean plain, where an accumulation of short-term halts has been interpreted as representing hunting stands (Ronen and Lechevallier 1991). Still, at sites such as Mallaha, in the Hula Valley, the sedentary lifestyle was maintained, most likely because of its location in a rich and variegated environment (Valla et al. 1999).

This settlement pattern differed sharply from that of the ensuing Early Neolithic (also known as the Pre-Pottery Neolithic A). The Neolithic sites were often established on alluvial fans and were generally larger than any of the late Natufian camps, which were located at ecotones (Henry 1989). The shift in the late Natufian is often linked with the well-documented climatic oscillation of the Younger Dryas (Bar-Yosef 1996, Taylor et al. 1997). This event was part of the ongoing oscillations marking the end of the Pleistocene climate regime and lasted for about 1,000 years; both its appearance and its termination were quite abrupt. The Younger Dryas is associated with climatic deterioration, a return to glacial conditions, but undoubtedly there were short-term ameliorations within this long period. In considering the influence of climate (i.e., environmental changes) in this time period in the Levant we need to take into account both the general trend and the short-term fluctuations postulated within it (Bar-Yosef 1996, Grosman and Belfer-Cohen 2002).

The late Natufian system is considered the embryo of cultivation in the Levant. Current evidence from the late Epi-Palaeolithic occurrences at Abu Hureyra (Hillman 2000), Mureybit (Colledge 1998), and other early farming communities indicates that the shift to cultivation took place during the final stages of the Natufian. The evidence retrieved from the early Natufian sedentary base camps concerning burial practices and artistic activities implies a distinctive social structure, and one wonders whether the instability of subsistence strategies of the late Natufian influenced that structure. Did the late Natufians maintain their ancestral social structure in spite of becoming more mobile?

Spiritual and cosmological perceptions, incorporating mythical lore and creation stories, are embedded in a society's very fabric, and the rate of change in social behavior is much slower and more restrained than that of change in subsistence strategy. Indeed, it has been argued that some communities maintained their ties with their original hamlets and returned there to bury

their dead, as is evidenced by the growing number of secondary burials during the late Natufian (Bar-Yosef 1998). I suggest that while there was a collapse of the large central settlements in the late Natufian due to the instability of subsistence strategies, ritual remained a powerful device for producing social cohesion. Not only was tradition maintained but ritual practices were even intensified. New evidence from the late Natufian site of Hilazon Tachtit Cave is of considerable significance to this issue. Because of its small dimensions and the burial ground it contains, Hilazon Tachtit Cave provides clues to the core of the late Natufians' beliefs and their adherence to the Natufian tradition.

HILAZON TACHTIT CAVE

Hilazon Tachtit Cave is located on the right bank of Nahal (wadi) Hilazon, western Galilee, Israel, some 14 km from the Mediterranean shoreline. It faces east and is situated at the foot of a limestone cliff on the right bank of the valley, ca. 120 m above the stream channel. The site is only some 7 km from the major Natufian base camp of Hayonim Cave and Terrace (Bar-Yosef and Valla 1991). Mallaha is 40 km to the northeast in the Jordan Valley (Valla et al. 1999). The Mt. Carmel sites of el-Wad, Nahal Oren, and Kebara lie only ca. 35 km to the southwest (fig. 1).

Excavation in the large chamber of the cave (an area of 44 m²) revealed two main stratigraphic units: layer A, which contained mainly ashes and goat dung because of prolonged herding activity in the area (which began, according to occasional pottery fragments, in Byzantine times), and layer B, an archaeological layer containing the late Natufian remains. The Natufian layer, 0.3–0.9 m thick, had been disturbed by historical digging in several places, and therefore the full extent and thickness of the original deposits are unknown. Nevertheless, given that there are no other prehistoric entities represented in the stratigraphic sequence, it was easy to isolate the historical intrusions. Accordingly, only the uppermost level of the excavated Natufian occupation (20 cm) was disturbed, leaving the structures and the burial ground intact. It should be noted that within the excavated area only a shallow depression in the cave floor—an area of ca. 30 m²—contained Natufian remains. Elsewhere bedrock was found immediately beneath layer A. The single available radiocarbon date of 10,750 ± 50 B.P. (uncalibrated), obtained from a large (10 × 12 × 19 cm) charcoal lump found in one of the structures, supports the observation that layer B is of late Natufian age.

Natufian sites in the Mediterranean core area revealed a distinct domestic architecture, with circular or semi-circular structures, hearths, built-up graves, and paved or lime-washed pits (probably storage bins) (Valla 1995). Although Hilazon Tachtit Cave is much smaller than the average core-area base camp, two small structures (ca. 1.5 m in diameter) built of undressed limestone cobbles, similar to those exposed in the base-camp sites of

Hayonim Cave and Mallaha, were uncovered. Structure A (fig. 2) is semicircular and was delineated by imported large stones that followed the natural outline of the bedrock. An artificial oval cut into the breccia formed an inner basin within the structure. Structure B is also bordered by the local bedrock and a series of undressed stones. The two structures are too small to have served for habitation and probably had a different function (e.g., as at Hayonim Cave [Belfer-Cohen 1988]).

Similar to other Natufian core-area sites despite its small size, Hilazon Tachtit Cave contained burials, and human bones were scattered through the entire Natufian layer. More than 450 burials have been exposed in Natufian sites, probably representing just part of the original number of burials, since site deposits often contain scattered human bones (Edwards 1991, Valla 1998, Belfer-Cohen 1988). That Natufian mortuary practices were diverse is apparent from the various types of graves and the differences in the number of individuals per grave, the position of the skeletons, and the type of burial, primary or secondary. Both primary and secondary burials have been found both in graves and in built-up structures with stone floors or stone covers (Belfer-Cohen 1988).

Some of the burials were decorated with jewelry and personal objects of adornment and accompanied by burial offerings (Garrod 1957, Belfer-Cohen 1995). A unique situation is observed at Hilazon Tachtit, where graves containing both primary and secondary burials were uncovered in three different locations:

At the top of layer B, excavation exposed a burial of an individual lying directly on large stones between structure A and structure B (fig. 2). The skeleton is of a young adult (sex unknown) lying on its right side in a flexed position with both hands under its face—a common position for Natufian burials. Unfortunately, many of the skeleton's bones are missing, probably because of later disturbance. The scattered bones of a newborn were found in the area of the missing pelvis, and it seems that the newborn was buried with the young adult.

Collective burials were uncovered in the lower portion of layer B in the inner part of the cave (fig. 2), occupying an area of 3×2 m to a depth of 50 cm. The collective burial is made up of several individuals (preliminary estimate of MNI = 11) representing different age-groups (adults, adolescents, children, and infants). A few observations reveal the nature of the burials: (1) The bones of

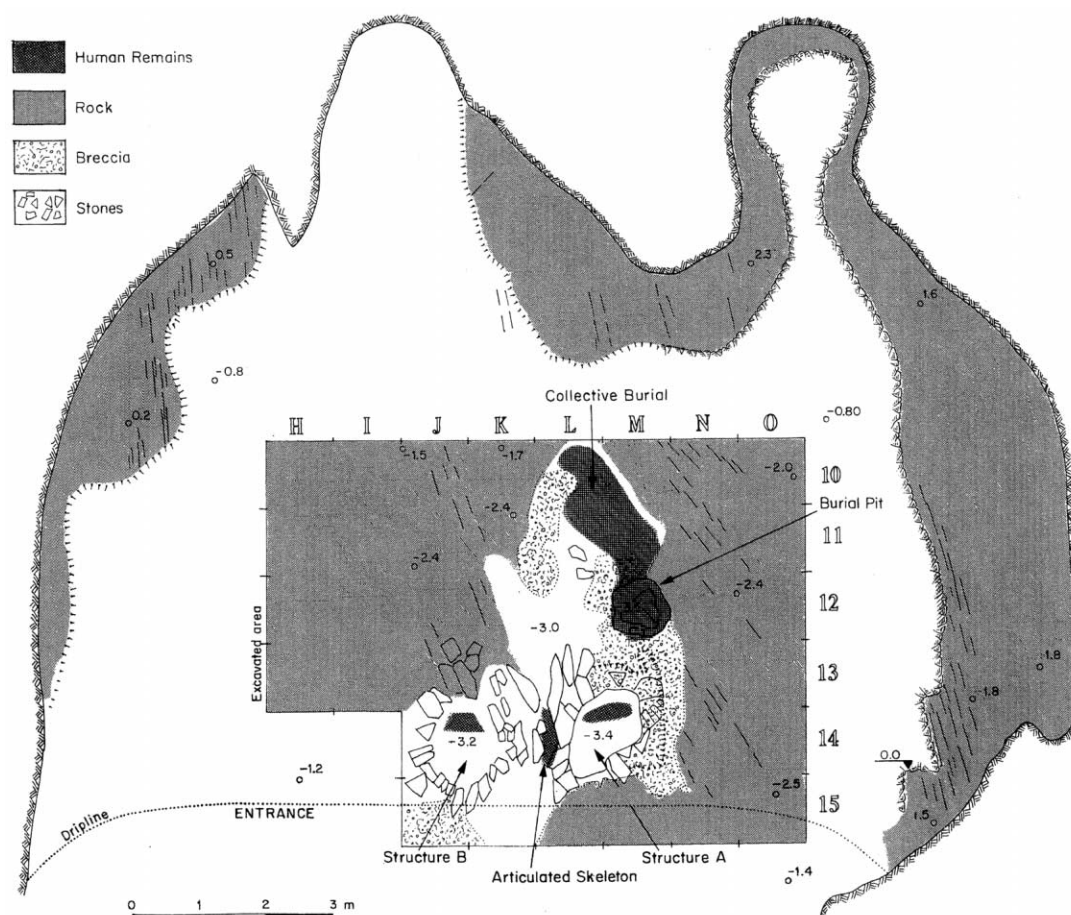


FIG. 2. Plan of excavation at Hilazon Tachtit Cave.

several hands and feet were still in articulation. Since the tendons of the hands and feet are typically among the first articulations to decay, this can be taken as an indication of a primary burial. (2) Bones appearing to belong to one individual, according to size and age estimates, were all found in close proximity. (3) Given the number of buried individuals, many bones are missing, especially long bones and skulls. It appears that this collective grave served as a primary burial ground that was later reopened and skulls and long bones (skeletal parts that are usually found in secondary burials) removed from it.

Secondary burials, consisting primarily of long bones and skulls, were uncovered in both the oval basin cut into the breccia in structure A and the pit in structure B. Although primary and secondary burials have been reported from early Natufian sites elsewhere (Belfer-Cohen 1989, Belfer-Cohen, Schepartz, and Arensburg 1991, Byrd and Monahan 1995), Hilazon Tachtit is the first site at which the complete variety of burial practices during the late Natufian occupation is observed. We are testing the possibility that the primary and secondary burials are complementary and represent the same individuals (Belfer-Cohen et al. n.d.).

A rich faunal assemblage was retrieved from Hilazon Tachtit Cave; preservation is quite good overall, as is indicated by the abundance of delicate avian bones. Mammalian remains bear signs of attrition and damage that according to the taphonomic evidence (e.g., cut marks, cone fractures, and fragment size) were caused by human activities such as processing and trampling rather than by postdepositional processes (Munro 2001). A variety of species, in particular gazelle and tortoise, were transported to the cave and clearly butchered for meat. The analysis indicates great similarity to the faunal assemblage from the late Natufian occupation at Hayonim Cave (Munro 2001).

Six thousand lithic artifacts, representing a relatively low concentration of ca. 200 artifacts per m³, with a high ratio of tools to debitage items (1:4), were studied. The flint artifacts are generally small and seem to have been knapped from flint pebbles that were brought into the cave from the streambed below. As a rule, Natufian lithic assemblages are characterized by high frequencies of microlithic tools, in particular lunates, which are sometimes considered the Natufian lithic index fossil (fig. 3). At Hilazon Tachtit Cave, microliths make up 40% of the 834 tools identified. Nongeometric microliths, mostly abruptly retouched bladelets, are by far the largest tool class, accounting for 30% ($N = 246$) of the tools. The geometric component makes up ca. 10% of the tools, about 80% of them lunates and ca. 20% triangles. Nineteen of the backed blades ($N = 50$ [2.4%]) retain harvesting luster and can be considered sickle blades. The dominance of backed short lunates and the absence of Helwan retouch assign this assemblage to the later part of the late Natufian (Belfer-Cohen 1988, Valla 1984). Ground stone utensils recovered in the cave ($N = 19$) include mullers, pestles, and a mortar with red ochre

stains covering its inner surface (fig. 4). The 29 bone tools consist of awls, points, and a perforated needle (fig. 5).

The Hilazon Tachtit Cave inhabitants collected curiously shaped natural stone objects, most likely because of their "aesthetic" appeal. These items ($N = 6$) were found in the collective-burial area and may have belonged to the buried individuals. They appear to be unmodified, except for a fossil flint pebble with some fine distal retouch (fig. 4). Ornaments consist mainly of shell beads, probably from the Mediterranean Sea. The most common are *Dentalium* shells, found in the collective-burial area. The tips of the dentalia, which are usually cut during the manufacture of beads, were recovered as well, indicating that the beads were made on site (D. E. Bar-Yosef Mayer, personal communication). A unique pendant (fig. 6) made from the lower carnassial tooth of a canid was found inside structure A, very close to two human bones (Grosman and Munro n.d.). The pendant is of considerable interest in view of the claims that the Natufians were the first to domesticate the dog (Garrod 1957, Davis and Valla 1978, Tchernov and Valla 1997). The joint human-dog burials at Mallaha and Hayonim Terrace are concrete cultural expressions of an intimate relationship between humans and canids, possibly reflecting a change in the symbolic relationships between humans and nature (Valla 1998, Valla, Mort, and Plisson 1991).

The location of Hilazon Tachtit Cave atop a high, steep escarpment with an excellent view of the valley as it opens to the coastal plain is of interest given the importance ascribed to the role of natural features in past cosmologies (Bradley 2000). It suggests that the site had a specific function, and while it served as a camp for short-term hunting forays it was also used as a burial ground. Although small, it contains all of the characteristics of early Natufian base camps, suggesting it to be a diminutive version of such a camp.

DISCUSSION

The nature of the occupation at Hilazon Tachtit Cave accords with a reversion to a more mobile way of life in response to environmental changes caused by the climatic deterioration of the Younger Dryas (Bar-Yosef 1995). During this period most Natufian base camps in the core area were abandoned, and there was a return to less specialized economic strategies that entailed short-term occupations by mobile hunter-gatherer bands. This settlement pattern implies a scheduled use of a variety of seasonal resources. Accordingly, it explains the repeated return of the bands to the Jordan Valley sites, excluding the possibility of a year-round or at least a prolonged occupation.

Both the hill sites and the sites in the Jordan Valley represent shifts in the Natufian exploitation of the environment throughout the time period predating the establishment of Neolithic society. Small bands of mobile

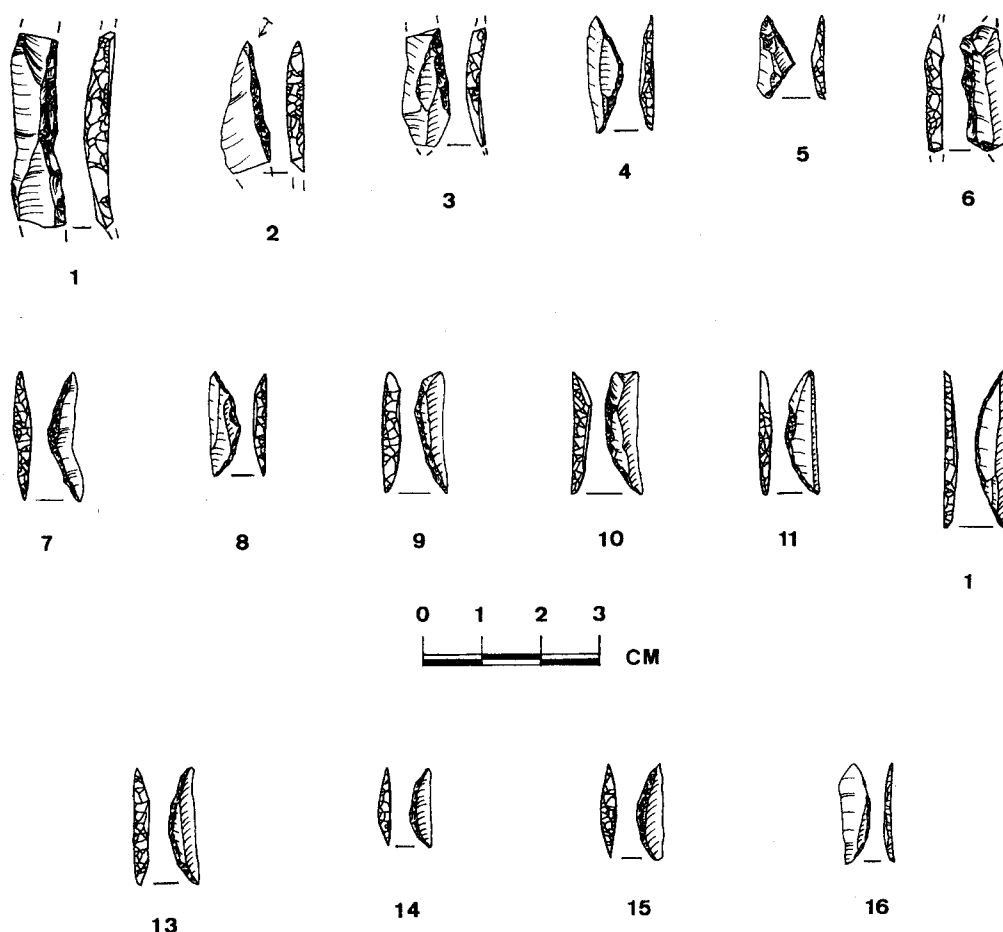


FIG. 3. *Microlithic tools. 1,2,3,6, backed bladelets; 4, 5, 7, triangles; 9–16, lunates.*

hunter-gatherers were alternating between the various geographic zones, going back and forth between the hills and the valley. These shifts came to an end in the Jordan Valley with the growing reliance on the exploitation of cereals. Indeed, in the following Neolithic, full-fledged sedentary agricultural communities were concentrated mainly in the valley and its vicinity.

The Natufians' social responses to the economic constraints varied. It seems that in the hilly zone the late Natufian retained the traditional customs of the early Natufian almost entirely. At Hayonim Cave and Hilazon Tachtit Cave there is evidence of intensive use as burial grounds—many formal burials and numerous human bones and teeth scattered in the occupational deposits (Belfer-Cohen 1988). In contrast, although the excavated areas of the lower Jordan Valley sites represent only small portions of the sites, no burials or structures were found and only a handful of scattered human bone fragments were recovered from the deposits (Crabtree et al. 1991, Grosman 1997). In addition, the cultic importance of the Hilazon Tachtit Cave is apparent in the energy invested

by the occupants in modifying the inside of the cave by digging into its surface and erecting two small structures.

A speculative scenario suggests that while there was a collapse of the large central settlements, ritual continued to produce social cohesion. Mortuary rituals often serve as both symbolic and physical expressions of the views and beliefs of human bands (Metcalf and Huntington 1991, Tainter 1978, among others), and it is evident from the late Natufian sites of the core area (Hilazon Tachtit Cave included) that mortuary rites were the order of the day (Belfer-Cohen, Schepartz, and Arensburg 1991). The rituals provided a framework for establishing, strengthening, and extending links between bands by elaborate codes of social reciprocity ensuring participation in collective ceremonies. They played a role in the unification of groups that were growing apart because of shifting subsistence strategies and greater mobility. Not only was tradition maintained but ritual practices were even intensified; caves sanctified the area in which they occurred and served as focal points in a "sacred landscape." Thus the small Hilazon Tachtit Cave, located on

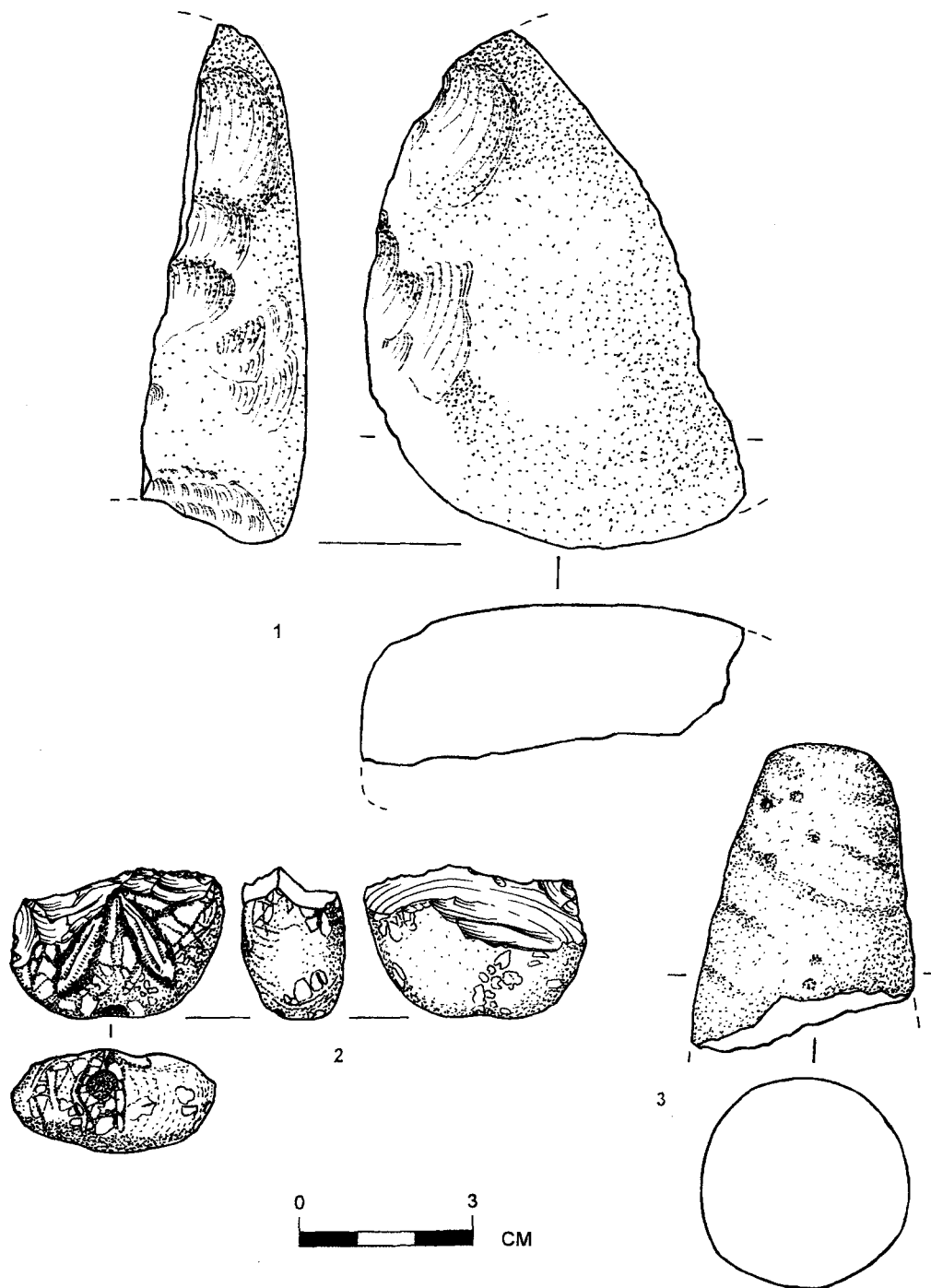


FIG. 4. Ground stone tools. 1, mortar with red ochre stains; 2, fossilized flint pebble; 3, pestle.

an escarpment, probably served as a landmark with political power and spiritual meaning.

The Natufian mortuary practices unearthed at Hilazon Tachtit Cave, in particular skull removal but also the custom of secondary burials, continued into the Neolithic. Secondary mortuary practices often reflect aspects

of ancestor worship and responsibility to the deceased. They also permit the scheduling of funeral events at a prearranged time when they will not conflict with other tasks and that is sometimes envisioned as a season of festivities. These practices took place in the hilly zone during the late Natufian period, and it was only during

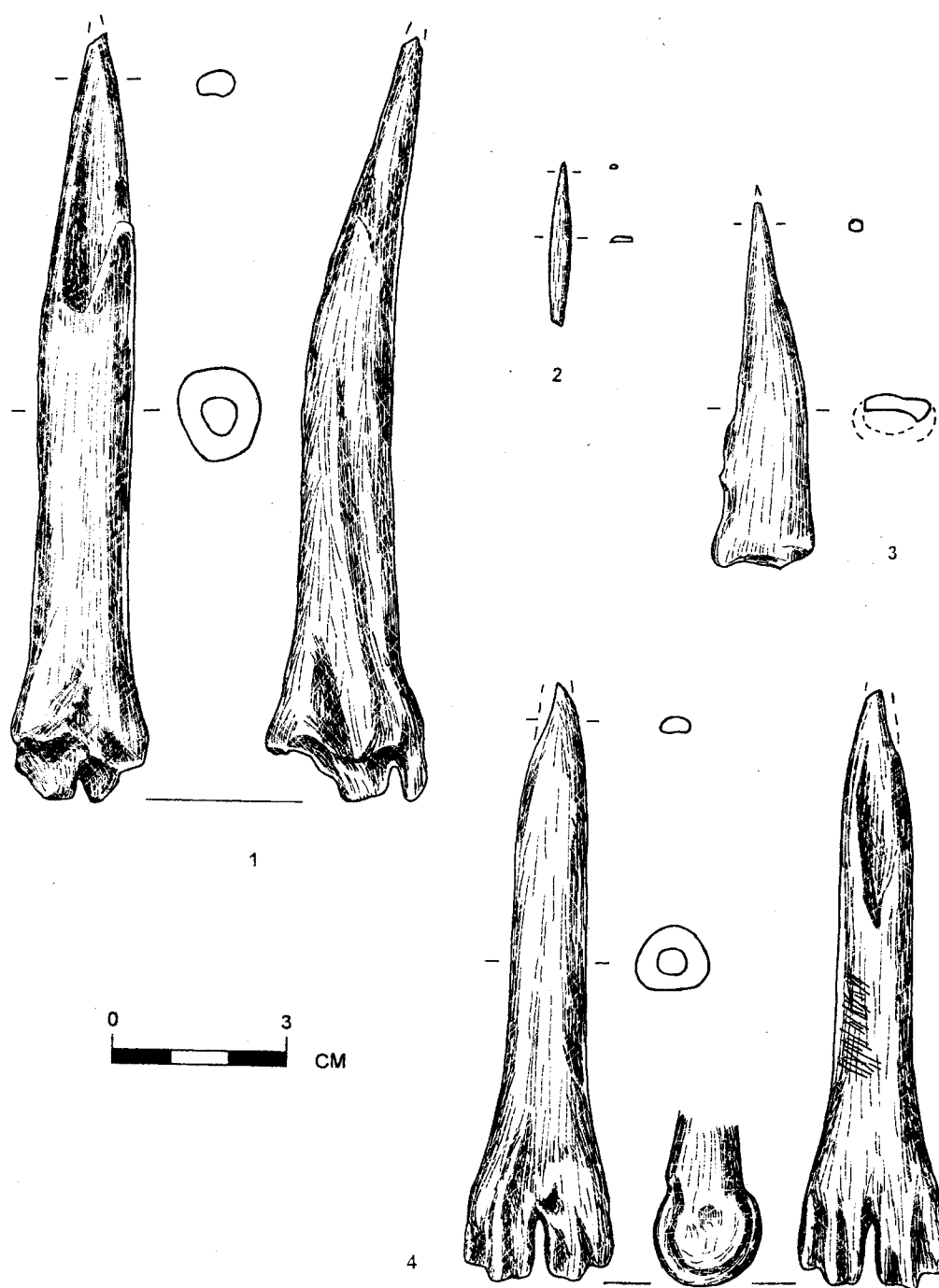


FIG. 5. *Bone tools.*

the initial stages of the Neolithic that things changed, the continuity of previous practices being retained only in the Jordan Valley settlements. Although climatic deterioration may impose rapid change in subsistence practices, the old traditions were retained in the geographic zone in which they were initially introduced and served as a mechanism for maintaining group identity in a time

of instability. The burial practices at Hilazon Tachtit Cave link the early Natufian tradition with the burial practices of the early Neolithic villages in the Jordan Valley.

Further research will be required for an understanding of regional patterns in human adaptation to climatic change, territorial circumscription, and changing life-

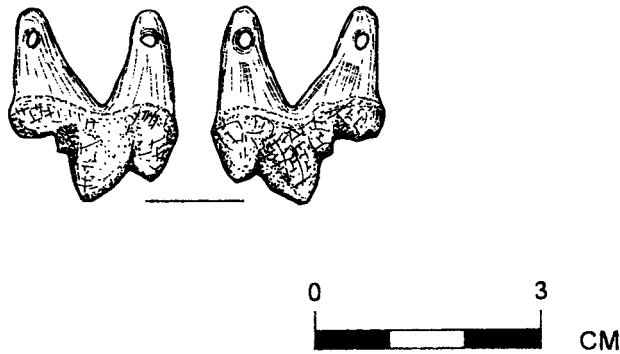


FIG. 6. Tooth pendant.

ways during the millennia immediately preceding the agricultural revolution. It is interesting that other cultural realms did not display major breaks such as those observed in subsistence strategies (e.g., the lithic industries show continuity from the Natufian to the Neolithic [Belfer-Cohen 1994]). The study of a transitional time span in human cultural evolution is a demanding task. It is difficult to reconstruct social changes, since they are triggered and sustained through a complex array of major and minor processes in the various domains of human existence. Progress in the understanding of this transition, as of any other, will depend on the continuing accumulation of data.

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Simulating Coastal Migration in New World Colonization¹

TODD A. SUROVELL

Department of Anthropology, University of Wyoming,
University Station, Box 3431, Laramie, Wyo. 82071,
U.S.A. (surovell@u.arizona.edu). 20103

The MV-II component of the Monte Verde site in southern Chile dates between 12,300 and 12,800 radiocarbon years B.P., but best estimates by Dillehay and Pino (1997: 45–49) place the occupation at approximately 12,570 radiocarbon years B.P., thus predating the Clovis complex (11,200 to 10,800 radiocarbon years B.P.)² by approximately 1,000–1,200 calendar years (Batt and Pollard 1996; Fiedel 1999; Taylor, Haynes, and Stuiver 1996). A number of additional sites from South America have produced radiocarbon dates contemporaneous with or slightly predating Clovis (Borrero 1999; Bryan et al. 1978; Correal Urrego 1986; Dillehay et al. 1992; Dillehay 1999, 2000; Kipnis 1998; Mengoni Goñalons 1986). If the initial entry into the New World occurred via the Bering land bridge and migration proceeded from north to south, how were prehistoric humans able to migrate to southern Chile while leaving very few if any traces along the way? Some would argue that there is already sufficient evidence documenting the presence of a pre-Clovis occupation in North America (e.g., Adovasio and Pedler 1997; Adovasio et al. 1999; Bryan and Tuohy 1999), but it is not my intention to join this debate (for comprehensive reviews see Bonnicksen and Turnmire 1999; Dincauze 1984; Dillehay 2000; Dixon 1999; Fiedel 2000; Meltzer 1993, 1995; Owen 1984; Rogers, Rogers, and Martin 1991; Waters 1985). There are at least four possible explanations for the spatio-temporal discrepancy between the early archaeological records of North and South America: (1) The age, artifacts, or stratigraphic integrity of many early South American archaeological sites are problematic. (2) Humans entered South America before they entered North America. (Obviously, this would have required a transoceanic migration.) (3) Earlier sites

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2. Two radiocarbon dates (11,540 ± 110 and 11,590 ± 90 radiocarbon years B.P.) from the Aubrey Clovis sites in Texas may extend the Clovis age-range (Ferring 1994) by approximately 300 radiocarbon years.

exist in North America but we have not yet discovered them or accepted their antiquity. (4) The initial migration into the New World occurred rapidly from north to south via a coastal route the traces of which have been inundated by rising late Pleistocene and early Holocene sea levels. The final hypothesis requires the assumption that early hunter-gatherers first expanded inland into South America and that migration into continental North America was significantly delayed. Of course, these hypotheses are not mutually exclusive.

In this report, I examine the feasibility of the coastal-migration hypothesis as the sole explanation for the existence of early South American sites using a computer simulation of migration along the American Pacific Rim based on coastal colonization models proposed by Gruhn (1994) and Dixon (1993, 1999). Simulating prehistoric migrations allows us to place limits on the past. By distilling complex migratory processes down to a few key parameters it becomes possible to identify what conditions must be assumed for human arrival at Monte Verde to have predated inland migration into North America. Model parameters are constrained by data from human demography and hunter-gatherer ecology. Put simply, although any value can be plugged into a simulation variable, these values can be realistically limited using independent data from human biology and ecology.

This research is based on a simple premise: If it must be assumed that migration occurred under conditions in which hunter-gatherers could not have lived, coastal migration by itself becomes an unlikely explanation of the observed patterning in the archaeological record. Although simulation cannot empirically falsify a hypothesis, it can demonstrate flaws in the theoretical or logical construction of a hypothesis by showing that its empirical predictions cannot occur under realistic conditions. It can also point to new avenues for addressing current colonization models. This study follows in a long tradition of using computer simulation and mathematical modeling to investigate the plausibility of hypotheses concerning New World colonization (e.g., Alroy 2001; Anderson and Gillam 2000; Martin 1973; Mithen 1993; Mosimann and Martin 1975; Steele, Adams, and Sluckin 1998; Surovell 2000).

THE COASTAL-MIGRATION HYPOTHESIS

As an alternative to the ice-free corridor, many writers have suggested that prehistoric humans may have entered the North American mainland by flanking Cordilleran ice, migrating along a chain of sea-level glacial refugia on the Northwest Coast. The first person to raise the possibility of a coastal entry was C. T. Hurst (1943: 250) in an article about the Linger Folsom site in the San Luis Valley of Colorado. Numerous others have discussed the coastal route (Chard 1963, Easton 1992, Heusser 1960, Laughlin 1988, MacGowan and Hester 1962, Mandryk et al. 2001, Rogers, Rogers, and Martin 1992), although the idea is generally attributed to Fladmark (1978, 1979, 1983), perhaps its most vocal proponent. In

recent years, however, the hypothesis has taken on a new role. Gruhn (1994:254), for example, has asked:

How could the [colonizing] population expand down into South America so long ago without leaving obvious traces in North America? . . . A littoral-adapted population would expand lineally down along a virgin coastline, with population growth and migration limited to a very narrow spatial front. One would expect that the front of population expansion moved fairly rapidly down along the western coastline of North America, and human groups passed through the Isthmus of Panama to reach south-central Chile and northeastern Brazil long before settlement of the continental interior of North America.

Gruhn (1988, 1991, 1994; see also Bryan 1991) has argued that this process can explain the presence of supposed Middle Wisconsin-aged sites in South America and the absence of such sites in North America. Dixon (1993, 1999, 2001) has made a similar argument with reference to the age of Monte Verde in light of North American evidence.

Archaeological evidence supporting the coastal-migration hypothesis has been difficult to find. Sites predating 10,000 radiocarbon years B.P. in western Canada and the northwestern United States are rare, possibly because of extensive sedimentation, deep burial, and low archaeological visibility in that region (Carlson 1996, Driver 1998). Detailed sea-level reconstructions of the Hecate Strait between the Queen Charlotte Islands and mainland British Columbia suggest that modern sea levels were not attained until approximately 9,400 radiocarbon years B.P., when they may have submerged earlier coastal sites (Josenhans et al. 1997). The recent discovery of a single flake in the Hecate Strait at a depth of 53 m, associated with a shoreline dating to 10,200 radiocarbon years B.P., is a tantalizing suggestion for early occupation of the Northwest Coast (Fedje and Christensen 1999: 647), but the find is too young to provide direct support for the coastal-migration hypothesis. The Manis mastodon site on the Olympic Peninsula of Washington may provide the best evidence for an early occupation of the Northwest (Gustafson, Gilbow, and Daugherty 1979). At this site, a mastodon was discovered in association with a single flake and what appears to be a bone projectile point puncturing one of its ribs. Radiocarbon dates on associated seeds, wood, and "micro-organics" suggest an age of approximately 11,800–12,000 radiocarbon years B.P. (Gustafson, Gilbow, and Daugherty 1979:158), but bone from this mastodon has yet to be dated directly.

In regions outside of the Pacific Northwest, other sites indicate early coastal occupations. Dates from maritime sites in California, Peru, and Chile suggest that humans may have inhabited coastal areas as early as 11,000 radiocarbon years B.P. (Erlandson et al. 1996, Keefer et al. 1998, Llagostera Martinez 1979, Sandweiss et al. 1998). These sites do not, however, predate Monte Verde or Clovis, with the possible exception of a date of 15,780

± 120 radiocarbon years B.P. from Daisy Cave on San Miguel Island near Santa Barbara, California (Erlandson et al. 1996). Also, the presence of early sites in coastal areas may indicate that people were exploiting coastal ecosystems at that time but says nothing about the route by which they arrived.

Spatio-temporal patterning in the earliest North American sites could lend support to a Pacific coastal migration. Interestingly, fluted-point sites in eastern North America tend to be younger than those of the west (Haynes et al. 1984), suggesting an eastward vector of colonization, but these data cannot be used to distinguish between initial coastal and ice-free-corridor entries because relatively few fluted-point sites have been dated west of the continental divide. Not helping the case, a number of sites in eastern North America have been proposed as pre-Clovis candidates, possibly exceeding 12,000 years in age (Adovasio et al. 1999, Goodyear 1999, McAvoy and McAvoy 1997, Overstreet and Stafford 1997). The paucity of empirical evidence regarding coastal migration highlights the utility of simulation for evaluating the hypothesis.

SIMULATING COASTAL MIGRATION

The simulation treats the coast as a series of 77 cells arranged linearly, each 200 km in length. Each cell contains the number of people inhabiting that portion of the coast. The simulation begins with a population of 50 individuals in the first cell at 47.5° north latitude, the approximate maximum southern limit of Cordilleran ice (Dyke and Prest 1987, Porter and Swanson 1998). In each iteration, time is incremented one year, populations grow, and migration occurs if conditions are favorable. Migration proceeds by individual and group decision making based on the goal of maximizing per capita overall return rates. Thus, migration does not occur unless it leads to increased caloric return rates over present conditions. Individuals can move between occupied and unoccupied cells and, under certain conditions, between occupied cells. Return rates are modeled as a function of population density, and therefore migration is ultimately fueled by demic expansion.

The simulation requires five parameters for operation: cell width, maximum population growth rate, leapfrog distance, and two functions relating population density to return rates for coastal and inland ecosystems, respectively. The length of cells has no impact on the results of the simulation. Cell width is the width of the coastal corridor. Maximum population growth rate is the annual percentage population increase under optimal return-rate conditions, and leapfrog distance is the greatest distance coastal populations can travel in moving around occupied coastal territory to reach uninhabited coast. Figure 1, *a*, represents the structure of the simulation. Coastal and inland return rates are modeled as truncated third- or fourth-order polynomial functions of population density, adapted from Smith's (1991:289–301) model of optimal group size for hunter-gatherers. Population growth rates vary from 0 to the maximum population

growth rate as a linear function of return rates.³ It is assumed that for any given population density, coastal returns exceed those of inland biomes, providing an incentive for populations to migrate along the coast in preference to moving inland.

Migration into unoccupied areas of coast occurs when an individual or individuals can increase overall return rates by moving to unoccupied territory. Emigration never occurs if the population density of a cell is suboptimal; in that case, the best strategy is to stay in place until population growth and/or immigration brings population density up to optimal levels. Once optimal density is reached, however, further population growth results in reduced return rates that foster emigration in the form of fission. A subpopulation will move to unoccupied coastline when the potential return rate for the excess number of individuals above the optimum exceeds that of the parent population.⁴ When a population migrates to unoccupied coast, it moves to the closest available cell. If immediately adjacent cells are occupied, a population may migrate to more distant cells within the designated leapfrog distance. Migration between occupied cells occurs when it will increase returns for all parties involved and the distance to the destination population does not exceed the leapfrog distance. A given cell will permit immigration if population density is less than optimal because recruiting migrants will result in greater return rates (fig. 1, *b*). Once population growth has pushed return rates below maximum inland returns, a subpopulation will migrate inland⁵ (fig. 1, *a*).

The simulation tracks the relative timing of three events: first inland migration, arrival in South America, and arrival on the coast at the latitude of Monte Verde. The location and age of Monte Verde are used as benchmarks for comparison, since it is the oldest and best-dated early South American site and among the most distant. Conservative estimates of distance place South America 7,600 km and Monte Verde 13,400 km from the entry point (fig. 2). First inland migration always occurs at the northernmost cells because population pressure is always greatest in the cell first occupied. For inland migration in South America to precede inland migration in North America requires an additional assumption—that inland return rates in South America exceed or approach coastal returns, resulting in a strong incentive to move into the continental interior. A key output variable is coastal distance, the distance traveled along the coast prior to first inland migration into North America. If

3. This assumption follows the work of Winterhalder et al. (1988) and is based on the premise that greater numbers of offspring can be supported per capita at higher rates of food acquisition.

4. Fission occurs when $R(d_{ct} - d_{c_{opt}}) > R(d_{ct})$, where d_{ct} is the coastal population density at time t , $d_{c_{opt}}$ is the optimal coastal population density, $R(d_{ct} - d_{c_{opt}})$ is the potential return rate of the migrant subpopulation at time t , and $R(d_{ct})$ is the return rate of the parent population at time t .

5. Inland migration occurs when $R_{I_{max}} > R(d_{ct})$ where $R_{I_{max}}$ is the maximum inland return rate and $R(d_{ct})$ is the coastal return rate at time t . The maximum inland return rate is used because there are generally sufficient numbers of individuals above the optimal coastal number to maximize inland returns.

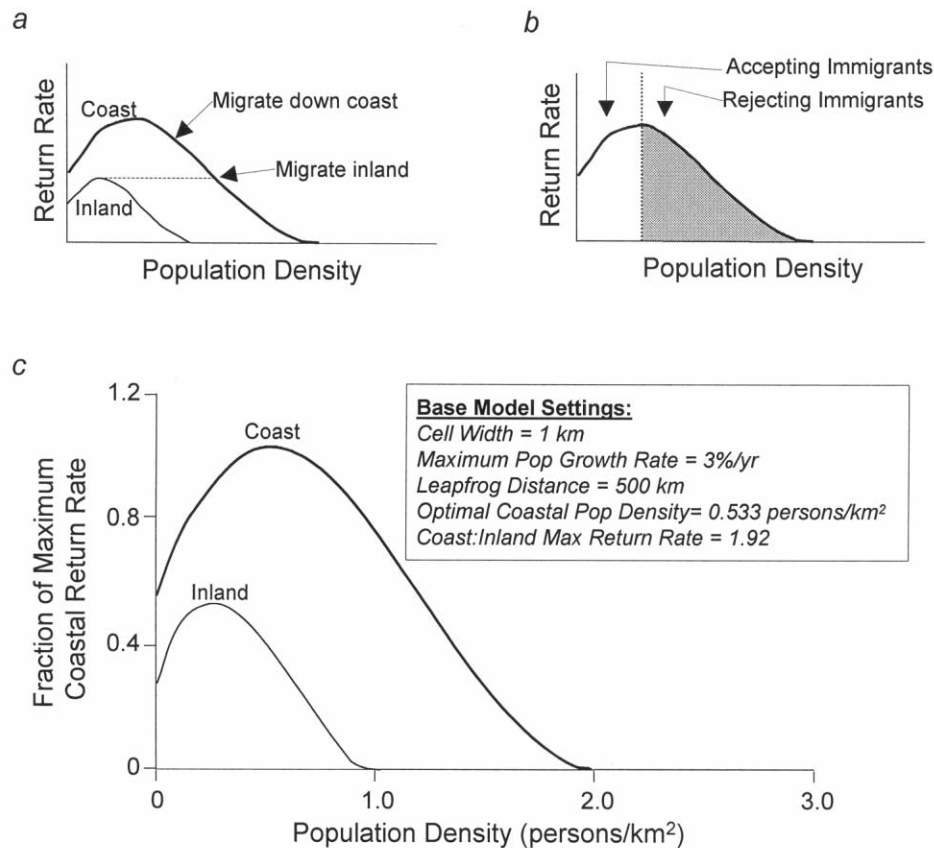


FIG. 1. a, The structure of the simulation. Coastal migration into unoccupied cells occurs when the number of individuals exceeding the optimum can improve their return rates by moving into unoccupied territory. Inland migration occurs when coastal returns fall below maximum inland returns. b, Population density versus status accepting or rejecting immigrants. Coastal migration between occupied cells occurs when an individual can improve returns by joining another population and that population can improve return rates by having an individual join, a condition met only when population densities for the destination cells are below the optimum. c, The “base model” structure and parameter settings. Coastal curve $r = (d + .2) \times (d - 2) \times (d - 2) / 1.579$; inland curve $r = (d + .1) \times (d - 1) \times (d - 1) \times 2.7$.

populations reach a coastal distance of 13,400 km southward 1,000 years prior to inland migration into North America, then the prerequisite condition for the coastal-migration hypothesis has been met.

A base model was created to test the effects of varying each parameter while holding the other four parameters constant (fig. 1, c). In the base model, cell width is set to 1 km, such that the coast is essentially modeled as a one-dimensional space. Assuming a very narrow occupation of the coast speeds coastal migration and limits the potential for the creation of inland archaeological sites until intentional inland migration occurs. Maximum population growth rate is set to 3% per year, well within the range of intrinsic rates of increase for human populations (Keyfitz and Flieger 1968). Leapfrog distance is set to 500 km. Maximum coastal returns are roughly twice those of inland ecosystems. Return rates are standardized to the maximum coastal return rate such that

they vary from 0 to 1. To determine the rate of population growth for any cell, the maximum population growth rate is multiplied by the fraction of the maximum coastal return rate. For example, if maximum population growth rate is set to 3% and population density is such that return rate is reduced to 50% of its maximum value, population growth rate is adjusted to 1.5%. What a return rate of 0 implies, however, is not that populations are unable to glean any food from their environment but that they are only able to maintain constant population levels. These settings are largely arbitrary and are irrelevant to the final outcome. They are used only as a point of departure for exploring the inner workings of the simulation.

Two parameters, maximum population growth rate and cell width, have no impact on the distance that coastal migration has advanced when initial inland migration occurs at the point of origin. Adjusting these pa-



FIG. 2. Estimated semilinear distances from the point of origin (approximately the latitude of Seattle) to various locations along the west coasts of North and South America.

rameters does, however, impact the timing of events. Narrower cells and higher population growth rates both result in increased rates of migration, both coastal and inland, but the timing of northern inland migration and arrival at southern destinations remain proportional, resulting in inland migration occurring after coastal migration has stretched only 1,000 km southward.

Adjusting leapfrog distance in the simulation, however, does impact coastal distance. Increasing leapfrog distance allows cells to extend the time period over which they can relieve population pressure by sending out migrants over longer distances, thus delaying inland migration. Also, it increases the number of cells that contribute to the migratory front along the coast, speeding rates of migration. If populations are allowed to leapfrog huge distances (e.g., > 2,500 km), migration rates can exceed 50 km per year. Nonetheless, it is not until leapfrog distance is pushed upwards of 4,000 km that groups reach South America before they move inland in the north (fig. 3, *a*). Even if leapfrog distance is increased to 5,000 km in the base model, inland migration still precedes arrival at Monte Verde. Compilations of mobility data from ethnographically studied hunter-gath-

erers indicate that single residential moves rarely exceed 70 km and cumulative annual distances moved seldom exceed 1,000 km for the most mobile groups (Binford 2001:table 5.01; Kelly 1995:table 4-1).

Modification of coastal and inland population-density/return-rate curves permits investigation of the effects of variation in the structure of coastal and inland ecosystems on the migration process. For example, reducing optimal coastal population densities is in effect increasing environmental predictability, since smaller groups are able to maintain high returns despite the fact that there are fewer individuals pooling information and variable foraging yields. Reducing optimal coastal population densities encourages populations to emigrate to uninhabited coast to maintain low densities. This also increases the migration rate. Figure 3, *b*, shows how this effect is modeled. In the base model, optimal coastal population density is set to 0.533 persons per km². As expected, migration rate increases with reduced optimal density, but the effect is minor until density drops to a value far less than 0.1 persons per km² (fig. 3, *c*). The distance migrated down the coast when first inland migration occurs increases dramatically as optimal density becomes very low, but to reach Monte Verde in the base model before inland migration occurs in the north, optimal density would have to be less than 0.0003 persons per km².

Hunter-gatherers rarely if ever exist at these densities⁶ (Binford 2001:table 5.01; Kelly 1995:table 6-4). To prevent inbreeding, a minimum population of 175 persons is necessary (Wobst 1974). In this light, if 2,000 km of annual mobility are allowed, placing 175 individuals within a 1,000-km-long strip of coast (2,000 km in round-trip mobility) results in an absolute minimum of 0.175 persons per km². This minimum value, however, is dependent upon the width of the coastal corridor. If a wider strip of land is occupied, lower population densities can be maintained because more land is available for use and greater numbers of people are supported. Order-of-magnitude increases in the width of the coastal corridor lead to order-of-magnitude decreases in minimum population densities. However, to make the coastal-migration hypothesis successful in the base model requires assuming that the coastal corridor was occupied over a width of almost 600 km. Because of the steepness of the conti-

6. The Yahgan, Gruhn's (1994) analogue of early coastal migrants, for example, existed at a density of 0.046 persons per km² (Kelly 1995:table 6-4), more than two orders of magnitude greater than the 0.0003 estimated minimum population density in the base model. Inland hunter-gatherers, unlike coastal groups, are not limited to a one-dimensional space, something that severely limits mating opportunities. For example, an inland band of 25 individuals at a density of 0.01 persons per km² can occupy a 50 × 50-km territory and maintain access to four neighboring groups for exchange of mates without traveling huge distances. If populations are hexagonally packed (Mandryk 1993, Wobst 1974), a single band at such densities can maintain access to six other bands or 150 other individuals without large mobility costs. For coastal groups without supplementary inland populations, a band of 25 hunter-gatherers living at a density of 0.01 persons per km² would have to travel upwards of 5,000 km per year to maintain access to 50 neighbors, assuming a 1-km width of coastal occupation.

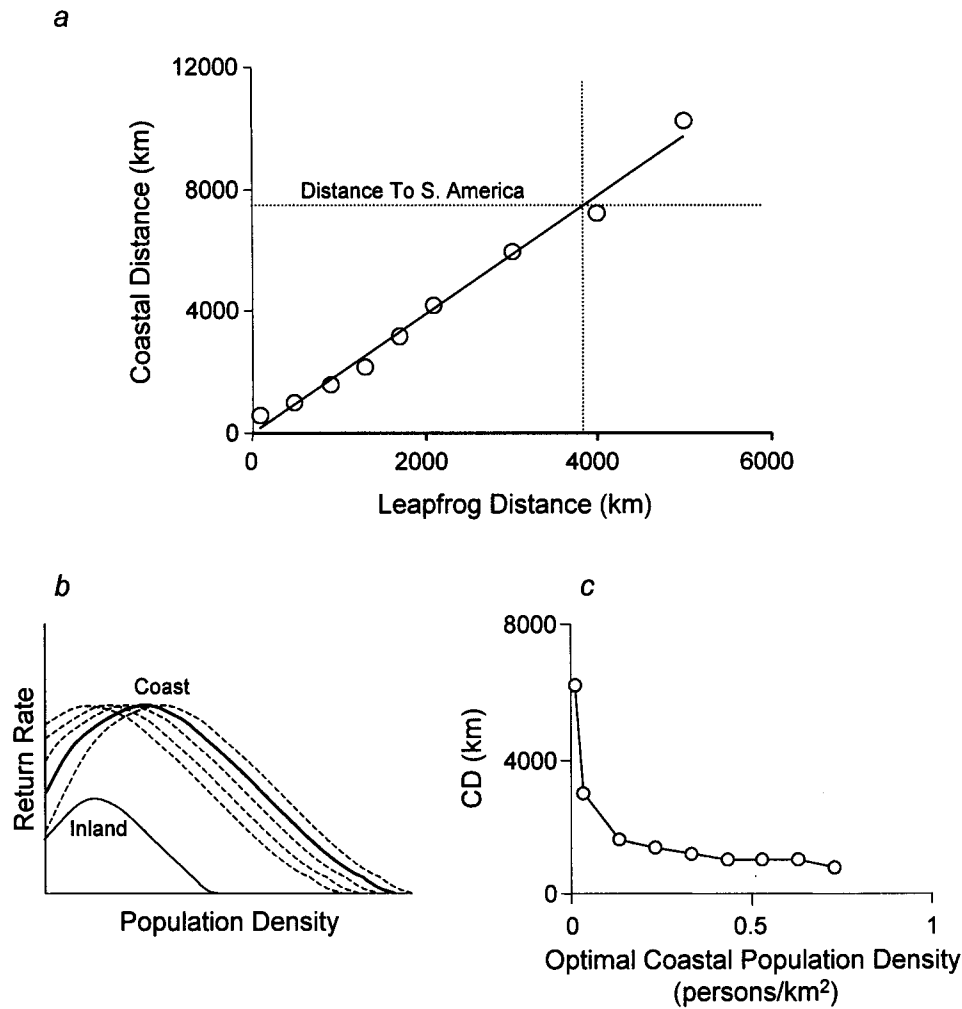


FIG. 3. a, The effect of leapfrog distance on the distance coastal migration has proceeded (CD) when the first migrants enter inland North America. b, Modification of the coastal curve to change optimal coastal population density. c, The effect of optimal coastal population density on the distance coastal migration has proceeded (CD) when the first migrants enter inland North America.

mental shelf on the west coast of the Americas, allowing any more than 50 km seems unreasonable because it would result in the creation of visible inland archaeological sites. At this setting, the minimum population density estimate is 0.0035 persons per km².

Another way to delay inland migration is to reduce inland return rates. As it becomes increasingly difficult for people to make a living inland as compared with on the coast, inland migration becomes a less attractive option. To model variation in coastal and inland return rates, the magnitude of the inland curve is systematically reduced by multiplying it by a constant (fig. 4, a). Arrival in South America does not precede northern inland migration until coastal return rates are approximately 950 times greater than inland rates (fig. 4, b). Inland migration, however, still predates arrival at Monte Verde if maximum coastal return rates are 1,000 times greater

than those of inland ecosystems. Estimates based on recent foraging populations suggest that coastal return rates can at best be only 36 times greater than those of inland ecosystems.⁷

7. There are relatively few data available on return rates for marine resources. Smith (1991) reports overall returns for hunting of a variety of sea mammals and aquatic fowl that range from 910 Cal per hour (Canada geese in summer canoe hunts) to 8,710 Cal per hour (eiders in fall canoe hunts). Kelly (1995:table 3-3) reports a number of postencounter return rates for inland resources, ranging from just over 1,000 to over 100,000 Cal per hour, indicating that terrestrial ecosystems can produce very high returns for hunter-gatherers. Most resources, however, range from a few hundred to a few thousand kilocalories per hour. Even if an eight-hour foraging day is assumed, half of which is spent searching for food, overall returns of 250 Cal per hour should be easily obtained. In fact, this is the absolute minimum in this case because adults require approximately 2,000 Cal per day for survival. If it is assumed that coastal

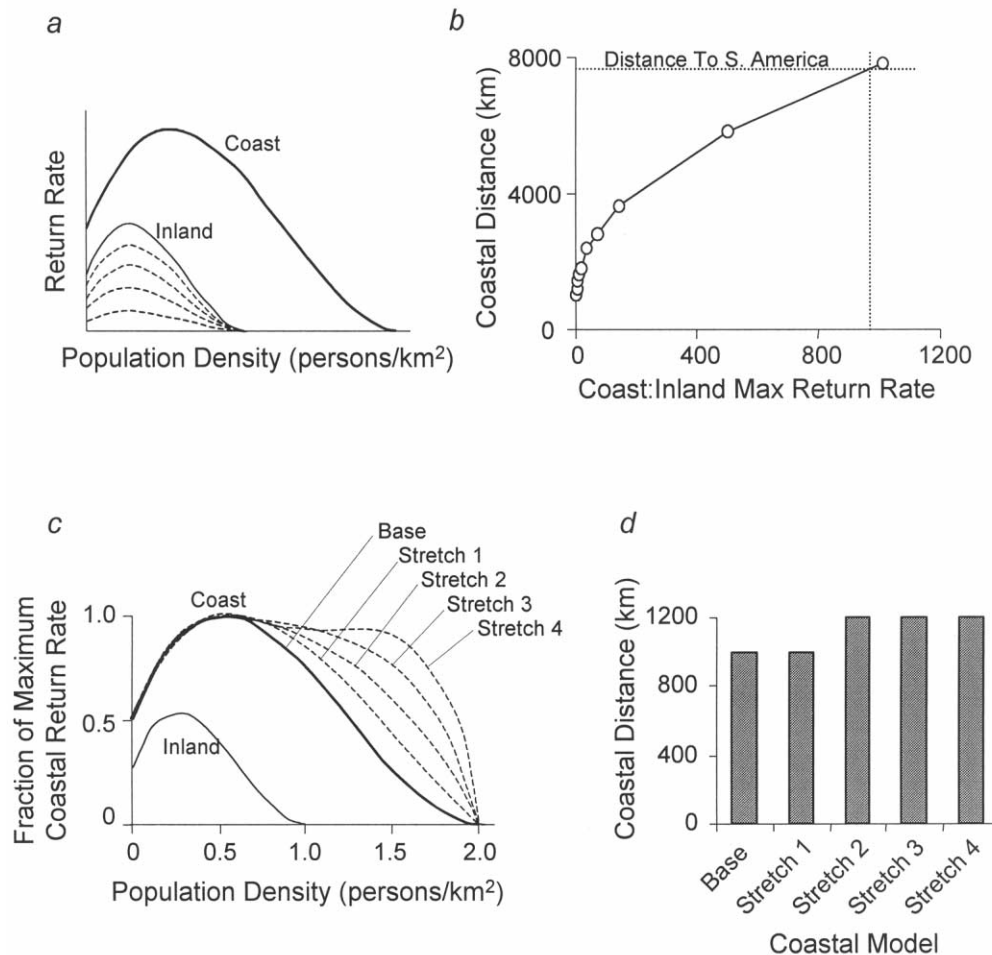


FIG. 4. a, Modification of the inland curve to change coastal:inland maximum return rates. b, The effect of coastal:inland maximum return rates on the distance coastal migration has proceeded (CD) when the first migrants enter inland North America. c, The “stretching” of the coastal curve to simulate increased coastal productivity. d, The effect of “stretching” the coastal curve on the distance coastal migration has proceeded (CD) when the first migrants enter inland North America.

Inland migration can also be postponed by increasing coastal productivity such that high return rates are maintained at high population densities (fig. 4, c). This delays inland migration because coastal returns do not approach maximum inland returns until coastal population densities are very high. The downside of increasing coastal productivity is that high population growth rates are maintained even at high population densities. Figure 4, d shows that “stretching” the coastal curve in this fashion has little effect on the distance that coastal migration has proceeded when groups first move inland in North America. In the best case, only 200 km are gained over the base model, with inland migration occurring when the front of coastal population expansion has pro-

ceeded only 1,200 km, approximately 100 km south of San Francisco.

None of the five parameters in the base model explored individually can produce the condition postulated by the coastal-migration hypothesis—arrival at Monte Verde before inland migration into North America. However, the possibility remains that by combining the effects of all the simulation parameters this condition can be met. A best-case scenario was created to test this proposition (fig. 5). Cell width was set to 50 km. Leapfrog distance was set to 1,000 km. Optimal coastal population density was set to 0.0033 persons per km². Maximum coastal return rates were set to 36 times those of the inland, and population growth was slowed to 0.5% per year to “buy time” between the entrance into South America and the first instance of inland migration in the north. The values chosen for each parameter are their estimated the-

return rates are maximized at 9,000 Cal per hour and inland returns at the minimum 250 Cal per hour, then coastal ecosystems at best are 36 times those of inland ecosystems.

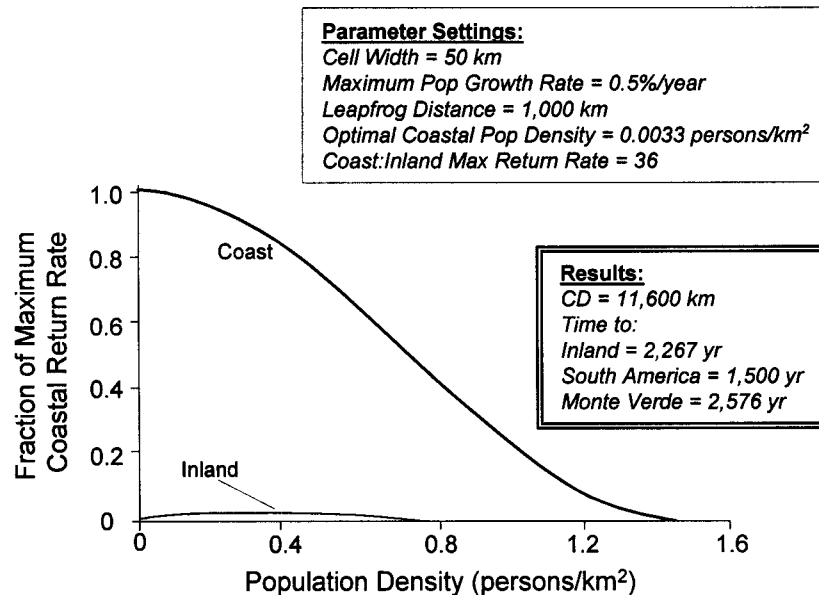


FIG. 5. The best-case model and results. Coastal curve $r = (d + .73) \times (d - 1.47) \times (d - 1.47) / 1.579$; inland curve $r = (d + .1) \times (d - 1) \times (d - 1) \times 0.14$.

oretical maxima or minima, and with these rather optimistic conditions coastal migration stretches 11,600 km before groups first move inland in the north. Arrival in South America predates inland migration by 767 years. Populations first set foot in South America in year 1,500, and northern inland migration occurs in year 2,267. However, Monte Verde is not reached until almost 309 years later, in year 2,576. If the maximum population growth rate is set to 3% per year, entry into South America predates inland migration by only 129 years, a time span barely detectable by radiocarbon dating. Nonetheless, assuming that inland migration occurred shortly after entry into South America, the simulation predicts that it is possible to produce the earliest visible New World archaeological sites in South America.

Although superficially the simulation has come close to producing the desired outcome—arrival at the latitude of Monte Verde prior to northern inland migration—there are problems with this formulation. First, Monte Verde supposedly predates Clovis by at least 1,000 years. In the best-case simulation, Monte Verde would postdate Clovis by approximately 300 years—a 1,300-year discrepancy. Furthermore, this form of the simulation has some bizarre predictions. For example, because coastal cells are so large (10,000 km²) and inland return rates are so low (1/36 of maximum coastal returns), inland migration does not occur until more than 13,000 people are present in a cell, and this condition is met in the founding cell in year 2,267. Furthermore, the simulation predicts that when the wave of population advance enters South America, there will be more than 67,000 people living on the west coast of North America and by the time people reach the latitude of Monte Verde

there will be more than 300,000. Clearly, there is no archaeological support for high population densities along the west coast of North America in the late Pleistocene or even the early Holocene.

These predictions suggest two ways in which the model may be unrealistic. First, if maximum inland return rates were higher, inland migration would occur sooner, and coastal populations could serve as a “demographic pump,” feeding inland migration and maintaining relatively low coastal population densities. Second, the curve relating population density to return rates may not be steep enough. If coastal return rates were modeled to drop very rapidly as a function of population density, coastal population growth would be slowed and high population densities would not be attained so quickly. Both modifications of the model, however, would promote early inland migration and slow coastal migration. If inland returns were greater, inland migration would occur earlier, and individuals moving inland would no longer contribute to demographic pressure driving coastal migration. If the coastal curve were modified in such a way that return rates dropped quickly as a function of population density, coastal return rates would rapidly approach maximum inland returns, causing inland migration, and coastal migration would be delayed by declining population growth rates.

DISCUSSION

The coastal-migration hypothesis alone appears incapable of explaining the spatio-temporal discrepancy between Monte Verde and early North American sites. For the hypothesis to be viable requires assuming (1) that the

initial migration into the New World occurred via a coastal route, (2) that inland return rates for North America were unrealistically low relative to coastal return rates, (3) that in South America and only in South America inland return rates were either equivalent to or exceeded those of the coast, (4) that optimal coastal population densities were excessively low, (5) that populations were very mobile and leapfrog distances were very large, (6) that population growth was very slow, and (7) that the occupation of coastal lands extended considerably inland without creating a clear archaeological signature. Even assuming all of these conditions, the simulation is unable to make arrival at Monte Verde precede inland migration into North America. Additionally, many of these assumptions are very difficult to justify. For example, the coastal-migration hypothesis postulates that first inland migration occurred in South America, but there is little reason to believe that South America would have favored inland migration and the entirety of North America would not. Allowing populations to leapfrog up to 1,000 km of coast seems very extreme. Also, recent work suggests that colonizing populations would be characterized not by sluggish population growth but by rapid expansion (Steele, Adams, and Sluckin 1998, Surovell 2000). Additionally, Late Pleistocene inland ecosystems were home to many genera of megafauna that had never experienced human predation (Berger, Swenson, and Persson 2001, Jelinek 1967, Kelly 1999, Martin 1973), and inland returns could have been quite high.

The coastal-migration hypothesis alone holds little potential for explaining the age discrepancy between Monte Verde and early North American sites, and Gruhn's (1994) proposition that it could explain the presence of sites of Middle Wisconsin age in South America and their absence in North America seems similarly remote. It cannot be stressed enough, however, that the simulation says nothing about the route of the initial migration into the New World or the route taken to South America. Coastal migration remains possible and perhaps likely, but if it had occurred we would expect to find the earliest inland sites in the New World not in South America but in western North America. The fundamental reason the model fails to produce the desired outcome is that the coastal distances are simply too great for southward migration to outpace population growth and inland migration in parent populations left behind.

Does the model negate the possibility of humans' ever having engaged in long-distance, rapid, linear colonization events? At least two examples of such colonization events are well known: the expansions across the Arctic coasts of northern Alaska and Canada by peoples of the Arctic Small Tool Tradition and the Thule (Maxwell 1985; McGhee 1984, 1996). The simulation, however, is not at odds with these events. The scarcity of fuel for winter fires on the treeless tundra would have tethered people to coastal areas. The peoples of the Arctic Small Tool Tradition seem to have depended in part upon driftwood for fuel, while those of the Thule tradition were reliant upon burning lipids from sea mammals (Maxwell

1985). This "coastal tethering" is analogous to reducing inland return rates in the simulation to near-zero levels, and the simulation would predict a rapid coastal migration with little inland colonization. The inland biomes of western North and South America, with the possible exception of the South American coastal deserts, have significantly higher productivity and habitability than the barren lands of the high arctic.

According to the simulation, if the primary corridor of colonization was the western coast of the Americas, the earliest archaeological sites both above and below sea level should be found in western North America and most likely in the Pacific Northwest. From our current limited sample of sites and radiocarbon dates, no such pattern emerges. Where does this leave us? One possibility is that our current view of the archaeological record is afflicted by sampling bias. Implied in most spatio-temporal analyses of human migration is that the archaeological record should produce a sample that accurately reflects the pathway of colonization, essentially an assumption of equal visibility in all regions. Ideally, the regions that were first occupied should produce the earliest dates while those occupied later should produce later dates. As Steele, Adams, and Sluckin (1998) have noted, however, the strength of the archaeological signal of the earliest colonizers is a function not simply of the length of occupation of a region but of the *cumulative occupation* expressed as the number of persons occupying a region multiplied by time—essentially a measure of person-hours. In this sense, regions favoring high population growth rates and high population densities will produce stronger archaeological signals than those occupied by groups at much lower population densities. This phenomenon could seriously bias our perceptions of the directionality of colonization because regions with long cumulative occupation spans would be more likely to produce early dates than those with short cumulative occupations span even if people first arrived in the latter. It seems unlikely that this phenomenon alone could account for the age discrepancy between early North and South American sites, but it could help to explain it.

This exercise has critically evaluated one version of the coastal-migration hypothesis and shed light on the process of colonization by demonstrating how it might occur as the cumulative product of the operation of simple rules governing individual decision making. Furthermore, it has provided some insight into assumptions underlying current informal models of coastal migration. Finally, even though the simulation has failed to demonstrate that coastal migration alone could have produced the observed archaeological record, this does not rule out the possibility of further simulation's producing that outcome or of further archaeological fieldwork's invalidating the findings presented herein.

Formal simulations can also provide avenues for future research through their direct implications. For example, the colonization model provides insight into the likely locations of the earliest inland sites if indeed a coastal migration occurred. As discussed above, inland migration is expected to occur first in regions close to the point

of origin because of the maximum time depth for population growth. Although coastal and inland ecosystems are treated as a constant for the sake of simplicity, the functions relating return rates to population density for these biomes would likely vary considerably up and down the coast. The model developed herein suggests that inland migration would be promoted in areas in which the disparity between inland and coastal return rates is minimized or even reversed. Paleoecological data on marine productivity and the composition of terrestrial plant and animal communities could certainly be incorporated into the model to refine this prediction.

One possible implication is that significant inland migration would be discouraged by coastal ranges in the Pacific Northwest, California, and Central and South America, where return rates would rapidly decline with eastward movement. Where corridors of habitable land exist between coastal ranges and the Pacific Ocean, however, early archaeological sites would be expected. More important, these ranges do not constitute an impenetrable barrier to the interior. Where large rivers empty into the Pacific Ocean, perforating coastal mountain chains, inland ecosystems would have appeared very attractive to prehistoric populations, since continental waterways serve as linear ecotones where many terrestrial and aquatic resources are available. The Columbia River, less than 200 km from the point of entry used in this study, is an obvious corridor into continental North America (see Bryan and Tuohy 1999). Other possible North American entry corridors include the San Francisco Bay, leading to the Central Valley of California, and the Colorado River. Such predictions may provide a relatively straightforward means of verifying coastal migration through intensive archaeological survey and excavation in the regions of these potential conduits to the interior.

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Excavations at the Palaeolithic Site of Attirampakkam, South India: Preliminary Findings¹

SHANTI PAPPU, YANNI GUNNELL, MAURICE TAIEB, JEAN-PHILIPPE BRUGAL, AND YANNICK TOUCHARD
B4-28, Siddheshwarnagar, Vishrantwadi, Pune 411015, India (spappu@vsnl.com) (Pappu)/Département de Géographie, Université de Paris 7, and CNRS-UMR 8591, Campus CNRS, 1 place Aristide Briand, 92195 Meudon cedex, France (gunnell@paris7.jussieu.fr) (Gunnell)/CNRS-CEREGE, BP 80, 13545 Aix-en-Provence cedex 04, France (taieb@cerege.fr) (Taieb and Touchard)/CNRS-UMR 6636 and CNRS-GDR 1051, MMSSH, BP 647, 5 rue du Château de l'Horloge, F-13094, Aix-en-Provence, France (brugal@mmsh.univ-aix.fr) (Brugal). 9 XII 02

India occupies a crucial place in the study of the Lower

Palaeolithic, particularly in relation to questions of hominid dispersal across Asia and regional adaptations to a diversity of natural habitats (Petraglia 1998). This potential has often been overlooked, predominantly because of a paucity of published reports and a preconceived notion of the rarity of well-preserved sites that are fossiliferous and have potential for being dated. In this context, our ongoing excavations at Attirampakkam near Chennai (South India), which are aimed at investigating early hominid behaviour in a new ecological context in India and at providing an age for the Acheulian in this region, are significant.

This report focuses on preliminary results of the first season's excavations at a well-preserved multicultural Palaeolithic site, Attirampakkam (13° 13' 50" N lat., 79° 53' 20" E long., 37.75 m above sea level), in the Kortallayar River basin of South India. Investigated for more than a century, the site has been regarded as a type site for the Lower Palaeolithic Madras Handaxe Tradition. Discrepancies noted in the stratigraphic and cultural sequences proposed by previous scholars (Banerjee 1964–65, Foote 1866, Krishnaswami 1938) led to a re-examination of the archaeology of the Kortallayar River basin (Pappu 1996, 1999, 2001a, b), and Attirampakkam was subsequently selected as the first in a series of excavations to be conducted at several well-preserved Palaeolithic sites in the region. Preliminary excavations at this site in 1999 revealed an Acheulian occupation in and on the surface of a 4-m-thick deposit of laminated clay indicative of a palaeofloodplain situation. This constitutes a previously unreported ecological habitat for the Indian Palaeolithic. The discovery of fossil teeth at the site was of great significance considering the extreme paucity of faunal remains at Indian Lower Palaeolithic sites. Subsequent excavations in 2000 led to the discovery of an Acheulian living floor with cores, tools, and debitage in association with a set of animal footprints.

Despite more than a century of prehistoric archaeology in India, we know little about its Lower and Middle Palaeolithic in comparison with those of Africa or Eurasia. Although active research on the Indian Lower Palaeolithic spans more than three decades, few systematic long-term regional studies coupled with excavations of well-preserved sites have been initiated. Notable among these are multidisciplinary projects in various parts of India (Allchin, Goudie, and Hegde 1978, Corvinus 1983, Misra and Rajaguru 1989, Paddayya 1982, Paddayya and Petraglia 1995, Sharma and Clark 1983, Petraglia, Laporta, and Paddayya 1999), which have focused on the environmental history of sites in their regional contexts and on the interpretation of site functions. In recent years, efforts have been made to model site formation processes (Pappu 1999; Paddayya and Petraglia 1993, 1995) and to obtain dates for the Acheulian (Mishra 1995). Excavations at open-air Lower Palaeolithic sites have yielded assemblages in a wide range of sedimentary contexts. Artefacts occur (1) at Chirki-on-Pravara in gravels and a cobble-rubble horizon (Corvinus 1983), (2) at Didwana 16 R in a stabilized sand dune (Misra 1995), (3) in the Hunsgi-Baichbal complex (Paddayya 1982; Pad-

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dayya and Petraglia 1993, 1995) in fluvial conglomerates and colluvium overlying bedrock and sealed by black soil, (4) at Isampur, in the same region, on a limestone surface with a matrix formed by calcareous brown silts, (5) in the Belan-Son complex (Sharma and Clark 1983, Williams and Clarke 1995), where they occur in the Sihawal formation of colluvial-alluvial clayey gravels and fanglomerates, (6) at Durkhadi Nala (Armand 1983) in a highly cemented pebble gravel, and (7) at Paisra in ferruginous sandy sediments (Pant and Jayaswal 1991). Along the east coast of India, in regions adjacent to Tamil Nadu, surface surveys and test pits (Thimma Reddy 1994) have revealed Acheulian sites in laterites or ferruginous gravels, usually in secondary or reworked contexts. The deposits underlying these are archaeologically sterile. Barring Singi Talav, in the Thar Desert, no Acheulian site contains artefacts in clay beds. At Singi Talav, Acheulian artefacts were found in clay deposits of the Amarpura formation down to a depth of 1.20 m below the surface (Gaillard, Misra, and Rajaguru 1983). This site forms part of a complex of Acheulian sites associated with playas and stabilized sand dunes along lakes in the Thar Desert (Misra and Rajaguru 1989, Misra 1995)—contexts quite different from that of Attirampakkam.

In recent years, interdisciplinary excavation projects have been initiated at only two Acheulian sites: Isampur (Petraglia, Laporta, and Paddayya 1999) and Attirampakkam. The results of these ongoing studies not only add a new dimension to Indian Palaeolithic archaeology but also have wider significance in that they highlight the need to consider data from regions outside Africa, Europe, and West Asia if a broader view of the Acheulian is to be gained.

THE REGIONAL GEOLOGICAL CONTEXT

The regional geological context consists of the NNE-SSW-trending Allikulli and Satyavedu Hills (200–380 m above sea level) in the west, which are cobble-to-boulder-sized fanglomerates or palaeodeltas of early Cretaceous age (Kumaraguru and Trivikrama Rao 1994). The lower-lying areas of the eastern Cuddapah piedmont in the vicinity of the Allikulli Hills are underlain by a shaly marine formation coeval and intertonguing with the conglomerate beds. The shales are capped by Tertiary to early Quaternary ferricretes. Older ferricrete (1.5–2.5 m thick), overlying bedrock, contains Acheulian–Middle Palaeolithic artefacts. Younger ferricretes contain Middle Palaeolithic artefacts and microliths. The region lies in an area of seasonally dry tropical conditions, receiving 105–125 cm of annual rainfall with a major peak occurring during late autumn and early winter (Pappu 1999, 2001b).

SITE STRATIGRAPHY AND PALAEOSEDIMENTARY CONTEXT

Excavations were initiated in 1999, when five test pits (2 × 2 m) were sunk, and continued in 2000, with a 29-m² area being excavated. Test trench T3 was excavated

to a depth of 7.30 m and yielded a total of 646 artefacts/natural clasts. Layers 1, 3, and 4 are archaeologically sterile, with sporadic redeposited artefacts. The artefact-bearing horizons were layers 2, 5, and 6. Layer 2 yielded possible Late Middle to Upper Palaeolithic tools. A transitional Late Acheulian–Middle Palaeolithic industry occurred in layer 5, while an Acheulian industry was noted on the surface of layer 6 at the junction with layer 5 and continuing down to a depth of 6.90 m.

The significant discovery was the unexpected occurrence of Acheulian tools in a laminated clay previously classified as a Lower Cretaceous shale of the Avadi or Sriperumbudur series (figs. 1, 2). The question whether the artefacts were coeval with this layer or redeposited was addressed by geochemical and magnetostratigraphic studies focusing on the nature of the deposit and on the likelihood that artefacts could have sunk from the overlying layers into the Cretaceous bedrock.

Samples were collected from trench T3 at 10-cm intervals (fig. 3). Clay and fine silt constitute 65% of the material in layer 6 while not exceeding 40% farther up-



FIG. 1. Closeup of layer 6 (laminated clay), test trench T3.



FIG. 2. Attirampakkam, trench T6: Artefacts in layer 6 (laminated clay).

profile. No grading can be detected. The geochemistry of the < 2-mm fraction shows a sharp change at ca. -2.75 m between a quartz-rich unit consisting of predominantly clastic material and a quartz-poor material dominated by fine material below it. The fine fraction of layer 6 is geochemically homogeneous throughout the profile. X-ray diffraction analysis of samples from layer 6 yielded 84% smectite, 14% kaolinite, and 2% illite. The presence of magnesium as the dominant lattice alkaline cation and the absence of vermiculite suggest that montmorillonite is the dominant smectite clay species. None of the trench walls, however, exhibit the vertical palaeocracks that are normally expected in the presence of smectite because of its shrinking-swelling properties and that could have allowed some down-profile redistribution of tools. The presence of cracks is more common in smectites containing 20–25% of exchangeable calcium and magnesium (Odom 1984), and sediment may never have been exposed to sufficiently long periods of drought for it to shrink significantly.

To summarize, the Palaeolithic tool sequence is contained in a profile consisting of two units separated by an unconformity at -2.75 to -3 m. The predominant fraction below ca. -2.75 m is fine silt rather than clay, and therefore the plasticity of the material is probably not as conducive as, for instance, organic mud to gravity-related sinking of foreign objects. Deeper than -7.3 m, greyish-black shale was struck, and it is considered to be the local *in situ* bedrock floor (Avadi shale). The overlying layer 6 therefore cannot be the *in situ* weathered roof of this shale: it corresponds to much more recent sediment and lies unconformably over it. Sedimentation was continuous; no palaeosols were identified in the profile. The geochemical homogeneity of the sediment also suggests stable palaeoenvironmental conditions. We thus infer that the Acheulian tools were used at the site and left lying until buried by overwash. As

episodic sedimentation proceeded, new tools continued to be discarded onto the fresh depositional surfaces.

The site of Attirampakkam is located less than 4 km from the outer convex bank of a major meander of the Kortallayar River. Most rivers of the south-east coast are typical suspended-load rivers. They flow on low gradients, deposit fine-grained sediment by overbank discharge, have predominantly sandy channels (Collinson 1996), and therefore are characteristic of semi-arid environments. Channel avulsion and abandonment are widely observed characteristics of these flat, near-coastal environments, which are sensitive to sea-level variations and shoreline changes. The archaeological site therefore in all likelihood developed on a meander cutting into the river's former floodplain. The negligible content of organic matter (< 0.2%) suggests episodic flooding rather than a perennial swamp with high biological productivity. The laminations are typical of sediment settled by low-energy sheet flow as encountered in floodplain ponds or abandoned channels. Assuming that a silt-clay layer 1–2 cm thick is deposited during a flood (Reineck and Singh 1973) with a return period of ten years, the homogeneous alluvial layer at the site would have taken 2,250–5,500 years to aggrade. The position of the site on the outer margin of a meander bend further suggests that it may have been involved in chute cut-off and thus corresponded to an oxbow lake. The ferricrete colluvium of layer 5 may coincide with the time of chute cut-off.

Considering that all the soft rock in the region was previously considered to be *in situ* Lower Cretaceous shale, the presence of Acheulian tools in a thick clay sequence raises the problem of the sedimentary environment and the age of occupation of the site. In an attempt at inferring a magnetostratigraphic age for layer 6 and thus for the tools embedded within it, 16 oriented samples were collected in the trench at 50-cm intervals from the surface to -7 m. Although no Pleistocene magnetic reversals could be identified because of insufficiently clear patterns in magnetic declination, the consistently low inclination values exclude a Cretaceous age for layer 6. The absence of any major difference in magnetic directions between layers 1–5 and layer 6 further suggests that these formations are all of Pleistocene age. A Cretaceous age for layer 6 must therefore be ruled out.

THE ACHEULIAN ASSEMBLAGE

In the light of the foregoing geochemical and stratigraphic evidence, the hypothesis that the artefacts of layer 6 sank into *in situ* Cretaceous shales from above via cracks, burrows, or root action is doubtful. This preliminary conclusion is further confirmed by the archaeological evidence.

If artefacts had sunk from layer 5 into layer 6, one would expect the pebbles and ferricrete pisoliths that predominate in layer 5 to have sunk with them. This, however, is not observed. While 257 pebbles are noted in layer 5, only 21 are seen in layer 6. Among these latter, 3 are less than 20 mm in size, 14 are 20–40 mm in size, 2 fall between 40 and 60 mm. Two further clasts fall

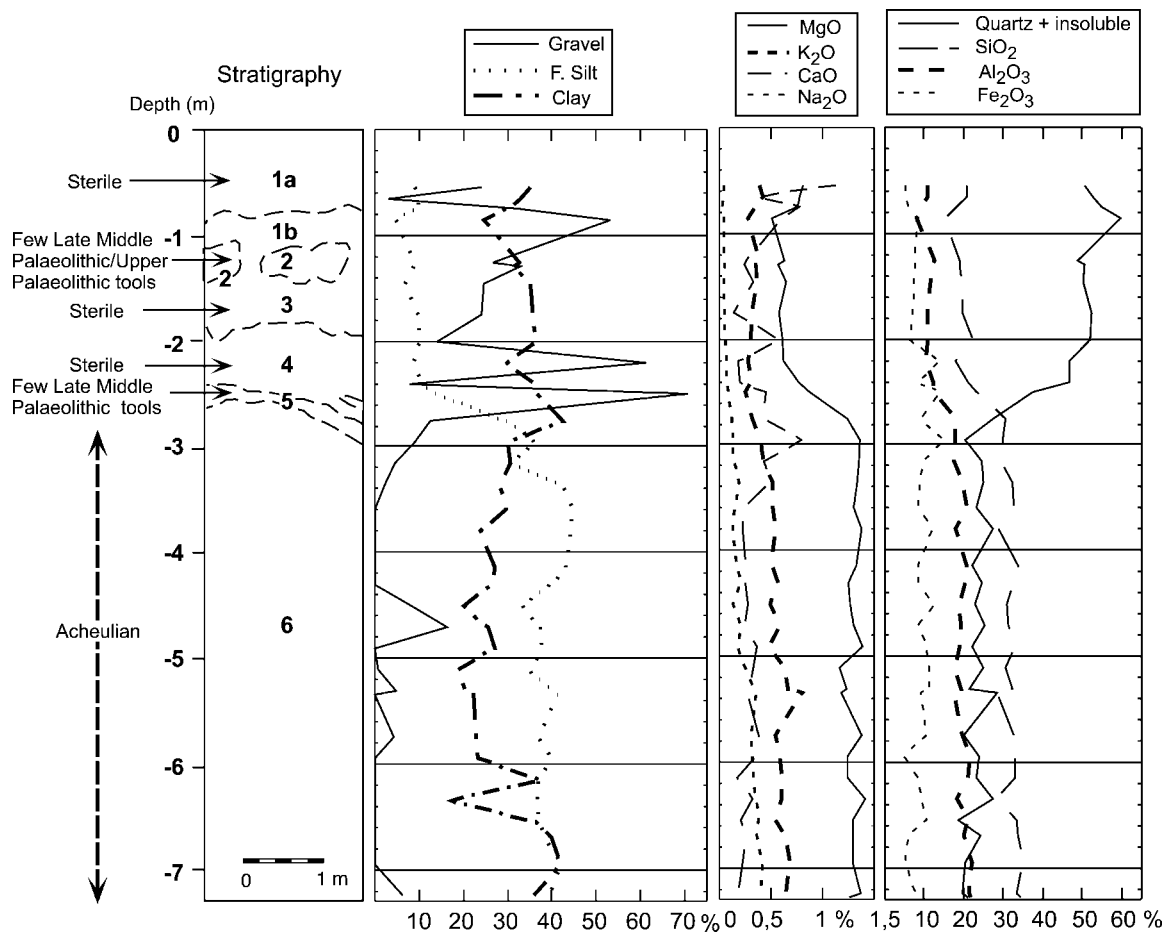


FIG. 3. Stratigraphy, texture, and geochemistry of trench T3 (east wall). 1a, 1b, sandy clay with concentrations of calcrete nodules; 2, sandy clay rich in loose iron and manganese pisoliths; 3, 4, calcareous sandy clay; 5, ferricrete; 6, laminated clay and fine silt. Sand and coarse silt texture curves (not shown) do not distinguish layer 6 from the overburden.

between 60 and 80 mm and, along with a clast from the 40–60 mm range, form parts of a conjoinable, culturally modified pebble that was probably discarded after preliminary chipping. These three artefacts are found at depths of 5.30 m and 5.50 m, with the complete piece measuring 85.90 × 53.75 × 40.00 mm. Two pieces greater than 80 mm in size are a large granite manuport (91.72 × 51.45 × 32.54 mm) and an elongated pebble with a prominent central ridge. Similar pebbles have been used to fashion several picks. Thus all the “natural clasts” > 60 mm are in fact culturally modified pieces or manuports. The artefacts in layer 6 do not bear any signs of the iron encrustation or patination characteristic of tools found in ferricretes and are often unpatinated (189) or unabraded (218) or both (184). In this they contrast sharply with the tools from layer 5, where artefacts in association with the ferricrete gravel tend to be both patinated and abraded or rolled (fig. 4). Artefact sizes and counts per unit depth were examined to investigate the possibility of size sorting as a result of sinking. The max-

imum numbers of tools occur between 4.00 and 4.20 m (35), between 4.40 and 5.20 m (100), and again below 6 m. Artefacts less than 20 mm in size are evenly distributed throughout the profile, while those between 20 and 40 mm in size are concentrated between 4.60 and 5.00 m (34). Artefacts greater than 80 mm in size and therefore heavier tools are not concentrated at the bottom of the profile but occur at depths of 4.00–4.20 m (15) and again below 6 m.

This trend does not, however, entirely deny any vertical movement of tools, for conjoinable pieces were noted in trench T3 that indicate vertical displacements of up to 60 cm. As has been demonstrated by refitting studies at Terra Amata, Gombe Point, and Meer II, vertical movement of artefacts does not detract from the value of the site and may be examined through specific site formation studies (Villa 1982, 1983; and see Petraglia 1998 on the Indian Palaeolithic). Moreover, most tools lie flat, parallel to the laminated structure of the sediment, and it is therefore difficult to detect any significant

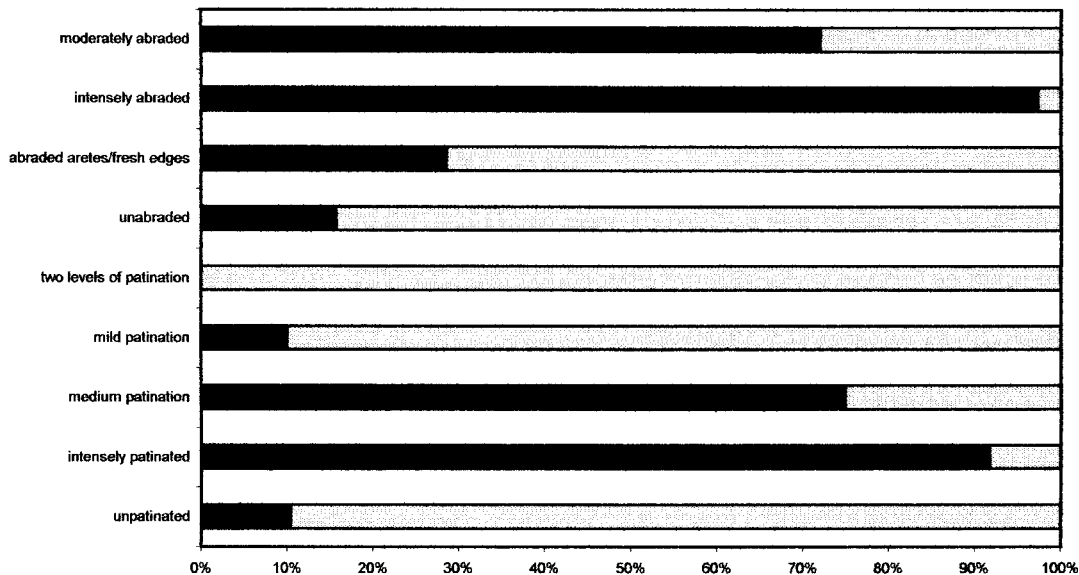


FIG. 4. Artefact abrasion and patination, layers 5 (black) and 6 (grey).

patterning suggestive of their having sunk into or within the clays of layer 6. A study of the orientation of artefacts collected from layer 6 in Trench t6 does not indicate any preferred orientation or particular flow direction.

The sample from trench T3 reveals that the principal raw materials for the Acheulian artefacts were quartzite (255 artefacts), quartzitic sandstones (6 artefacts), and quartz (25 artefacts). Raw-material sources included pebbles and cobbles derived from outliers of the Allikulli Hills, at a minimum distance of 2–3 km south and south-east of the site. Alternatively, clasts from a boulder conglomerate underlying the shales could have been utilized provided that exposures were available during the Pleistocene. Some degree of preliminary manufacture and trimming of tools at the site is indicated by the presence of an anvil on a rolled, rectangular cobble, pitted on one face, two hammerstones, and a few cores (table 1). The latter include prepared cores (Levallois, discoidal), irregular flake cores, flake and flake-blade cores, and a possible unstruck flake-blade core. One example displays shallow scars of a type commonly noted on cobble faces which are exposed to thermal changes resulting in splitting of cortical areas. Two artefacts may be classified as large core-flakes, with less than 50% cortex, which could have served as subsequent flake cores but from which no further flakes were detached. Broken tools are snapped across the proximal or distal ends. Debitage also includes unretouched flakes “knives” with edge damage that may possibly have been used.

Artefacts are on flakes, flake-blades, pebbles, or naturally available chunks (figs. 5 and 6). Older or broken tools were also reused, as were debitage flakes and chunks. Reuse of older artefacts as evidenced by differential patination is also noted and may be a reflection

of the absence of raw material at the site. Although the first season’s test pit yielded only two handaxes (ovate and miniature almond-shaped) and one unifacially flaked pointed and notched flake, the second season yielded a high percentage of bifaces. Two cleavers are parallel-sided, with oblique cleaver edge, and one is convergent with a straight cleaver edge. One example is a cleaver-flake, minimally flaked along the dorsal surface to create a cleaver-like working edge. Heavy-duty scrapers are on large side-struck flakes and are retouched with one or more rows of irregular retouch. One example appears to have two phases of patination. Core scrapers are on thick flakes and cores/chunks and are generally high-backed with abruptly retouched sides. Picks include artefacts on flakes, chunks/debitage, cores, or pebbles which have one pointed apex, generally created by notches. In addition to this, the edges may also be notched. Two picks on pebbles are conjoinable although separated by a vertical distance of 0.62 m, the complete tool having been split in half. Chopper-chopping tools are nonexistent, although a few cores do appear to grade into chopping tools, possibly indicating a continuum along a reduction sequence.

Light-duty tools include borers, knives, and denticulates. A characteristic trait is the choice of elongated flakes or chunks that are thick along one edge (which may also be abruptly chipped or cortically backed) while the opposite edge is sharp retouched or unretouched. No true points were noted, but there are three pointed flakes, all on end-struck triangular flakes. There is one flake-blade, intensely patinated and moderately abraded. Retouch is in general irregular and discontinuous, with one or more edges bearing scalar or abrupt retouch. A small component of the assemblage includes a few blades and

TABLE 1
Acheulian Artefact Assemblage (Layer 6, Test-Trench T3)

Artefact Type	Count	%
Hammerstones	2	0.70
Anvil	1	0.35
Manuports	2	0.70
Granite chunk	1	0.35
Flat quartz piece (7 fragments)	1	0.35
Cores	10	3.50
Elongate discoidal cores	2	0.70
Irregular multidirectional flake cores	2	0.70
Irregular flake core	2	0.70
Flake-blade core	1	0.35
Core-flakes	2	0.70
Levallois core	1	0.35
Core-chopping tools	2	0.70
Debitage	152	53.15
Chips	4	1.40
Chunks	27	9.44
Non-cortical flakes	34	11.89
Cortical flakes	15	5.24
Trimming/rejuvenation flakes	20	6.99
Blades	4	1.40
Broken flakes	6	2.10
Broken tools	13	4.55
Unretouched flakes	25	8.74
Unretouched blades/flake-blades		0.00
Unretouched knives	4	1.40
Finished tools	112	39.16
Uniface	1	0.35
Handaxes	2	0.70
Cleavers	2	0.70
Cleaver-flake	1	0.35
Knives	9	3.15
Heavy-duty scrapers/cutting tools	6	2.10
Push-planes	4	1.40
Bifacially flaked tools	4	1.40
Picks	8	2.80
Flake-blade	1	0.35
Borers	7	2.45
Denticulates	5	1.75
Notches	2	0.70
Pointed tools	3	1.05
Scrapers on flakes	22	7.69
Single convex	5	1.75
Irregular	2	0.70
Single straight	5	1.75
Round	4	1.40
Double straight and end	1	0.35
Pointed	1	0.35
Convergent		0.00
Double straight and end (notched)	1	0.35
Scraper-borer	1	0.35
Core scrapers	6	2.10
Pieces with retouch	8	2.80
Miscellaneous	1	0.35
Chronologically later tools	20	6.99
Grand total	286	

Levallois flakes, all on quartz or quartzite that is finer-grained than that used for other artefacts. Whether these constitute a chronologically later element or part of the Acheulian is unclear. No change in technology or assemblage composition is noted within layer 6.

The assemblage from the test trench in layer 6 indicates that a limited degree of tool manufacture and trim-

ming was carried out at the site. Most raw-material clasts and cores were imported to the site. In comparison with other industries in India, this is a Late Acheulian industry with a Levallois element and flake-blades (Misra 1972, Paddayya 1984) and differs from the Middle Palaeolithic technology of the Kortallayar Basin (Pappu 2001a). Subsequent excavations of a 29-m² area in trench T6 yielded evidence of an Acheulian living floor at a depth of 3.50 m below the surface. Boulder cores with associated debitage, artefacts, and hammerstones were noted in association with a set of animal footprints. Excavations in 2002 exposed an area of 30 m² that confirmed the occurrence of the Acheulian within the clay (layer 6). Studies of the lithic technology of these assemblages are in progress and will aid in a better understanding of core reduction strategies at this site.

FAUNAL REMAINS AND IMPRESSIONS

Three fossilized teeth, brecciated and slightly compacted, were discovered: a bovine upper molar, possibly representing *Bubalus* (water buffalo) or *Bos* (occlusal morphology was not observable because of the matrix), an *Equus* sp. lower molar, and a left lower molar with a goat fold, caprine or *Boselaphus* (nilgai). These indicate at least three species suggestive of an open and wet landscape. Seventeen round impressions (15–20 cm in diameter) and a set of animal hoof marks are currently under study.

CONCLUSION

The site of Attirampakkam is unique in the context of the Indian Palaeolithic in terms of the occurrence of Acheulian tools in clay beds, indicating a new environmental context in the Indian Acheulian. Recent studies (Petruglia 1998) bracket the Lower Palaeolithic of India between ca. 150,000 and > 350,000 years ago, with a few dates (Mishra 1995) in excess of this. Palaeomagnetic

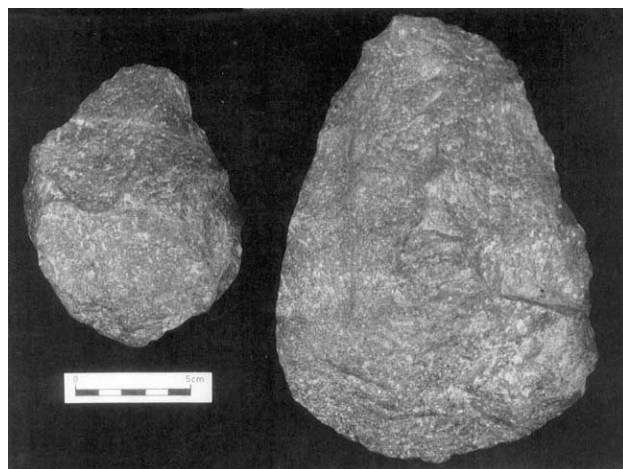


FIG. 5. Acheulian handaxes (layer 6).

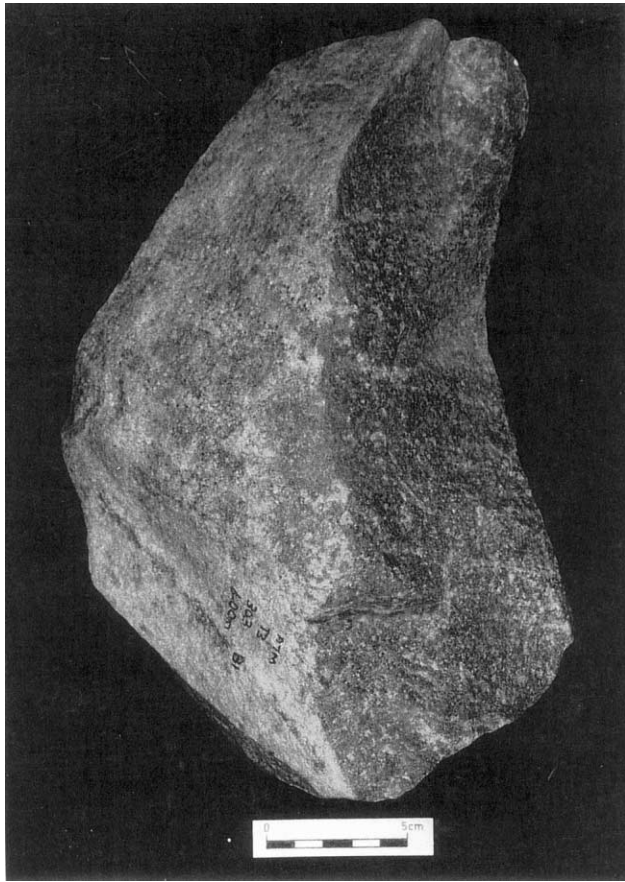


FIG. 6. Acheulian flake-core (layer 6).

measurements at Attirampakkam would contribute further geochronological constraints to this emerging pattern. Our studies indicate a flood-basin environment for the site, with incorporation of tools into clays derived from older shales that are alluvial in origin and Pleistocene in age. The only comparable record of artefacts in clay deposits in India is from Singi Talav, which has been interpreted as a site occupied by early hominids camping along the banks of a shallow pool in the Thar Desert (Gaillard, Misra, and Rajaguru 1983). Attirampakkam is also significant for the presence of fossil faunal remains, rare at Indian Palaeolithic sites, and Acheulian artefacts in association with animal footprints. Despite a century of research, few open-air Acheulian sites have been excavated on a large scale, and our knowledge of the age and nature of the Acheulian in India, of regional variability in hominid adaptations, and of the nature of the Lower-to-Middle Palaeolithic transition lags far behind that for other parts of the world. The unique ecological context and distinctly stratified deposits at Attirampakkam are of immense importance for an understanding of early hominid adaptive strategies in South Asia.

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Lower Palaeolithic Core Technology and the Origins of the Levallois Method in North-Western Europe

MARK WHITE AND NICK ASHTON

Department of Archaeology, University of Durham,
South Rd., Durham DH1 3LE, England (m.j.white@
durham.ac.uk)/Department of Prehistory and Early
Europe, British Museum, Frank's House, 38-56
Orsman Rd., London N1 5QJ, England. 10 11 03

The appearance of Levallois technology ca. 300,000–250,000 years ago (oxygen isotope stage 8) is commonly used to define the Lower-to-Middle Palaeolithic bound-

ary in Europe (see Ronen 1982) and arguably represents the only major innovation in lithic practices during the entire Middle Pleistocene of that continent (White and Pettitt 1995, Gamble 1999). Given the 300,000 years of stasis that precede it, this example of culture change is an event of singular importance that goes beyond lithic technology and may herald the emergence of more profound changes in hominid social, behavioural, and cognitive structures. Despite this, the origins of Levallois technology have of late been a remarkably neglected area of research.

Most recently published accounts of the origins of Levallois technology in Europe have tended to emphasize an *in situ* evolution from handaxe technology (Tuffreau 1995, Rolland 1995, White and Pettitt 1995; see also Debono and Goran-Inbar 2001 for the Near East). For Rolland (1995), the presence of finely made handaxes would have led almost inevitably to the accidental discovery of the Levallois method via large axial thinning flakes. Examples of such detachments (what Callow [1976] termed "pseudo-Levallois") can be observed in numerous Acheulean contexts, perhaps the best-known of which is at Cagny La Garenne, France (late oxygen isotope stage 12), where on occasion what appear to be preferential Levallois cores have been formed from handaxes broken during manufacture or sometimes from very thick complete handaxes (Tuffreau 1995). If such an emergence is accepted, then the development of Levallois technology in Europe would appear to have been a disjointed, multiphase affair involving the precocious but unstable mutation of handaxes (probably from the earliest European Acheulean) followed by the much later sedimentation and elaboration of the technique sometime around stage 8 (Rolland 1995). By stage 7 Levallois technology was widespread and all the currently documented variation was in place, suggesting rapid development, diversification, and dispersal (Tuffreau 1995). A completely different and quite separate evolution is described for Africa, where the Levallois method is suggested to have emerged gradually from simpler core-working strategies through a series of proto-stages (Rolland 1995).

While the timing of these events, especially in Africa, is still to be fully worked out, the picture of continuity in Africa combined with discontinuity and the apparent lack of any proto-stage in Europe ostensibly lends support to Foley and Lahr's (1997) "Mode 3" hypothesis. This advocates an exclusively African genesis for prepared-core technologies, with their subsequent introduction to Europe ca. 250,000 years ago as part of a major dispersal event by *Homo helmei*, proposed as the most recent common ancestor for Neanderthals and anatomically modern *Homo sapiens*. With this model Foley and Lahr explain the common use of Levallois technology by these two species in the Levant ca. 100,000 years ago but in doing so also implicate the Neanderthals more closely in the origins of anatomically modern humans, "modern" behaviour, and the African Middle Stone Age. In light of recent work on the Middle Stone Age (McBrearty and Brooks 2000), such a connection would demand a radical reevaluation of the way we look at the

European archaeological record from 250,000 years ago onwards.

This paper presents some observations on the technological origins of Levallois using the lithic assemblage from Botany Pit at Purfleet, augmented by some observations on the small collection of cores and refitting flakes from Frindsbury, England. It suggests that the core technology from these sites is a relatively simple and unrefined form of prepared-core technology geared towards attaining greater control over cores and their products; given their age and character it may be justifiable to call this “proto-Levallois” technology (Wymer 1968). (For present purposes we will adopt the slightly less loaded term “simple prepared-core” technology.) These conclusions carry implications for the origins of Levallois technology and the origins of the Neanderthals.

THE PURFLEET SITE

Purfleet is located in the Lower Thames Valley, 20 km east of central London. Since the 1960s a complex sequence of Pleistocene deposits has been exposed in a series of commercial pits (fig. 1). The deposits are interpreted to belong to an abandoned meander loop of the main River Thames and to form part of the Lynch Hill/Corbets Tey Formation (Bridgland 1994), which on lithological and biostratigraphical correlation spans oxygen isotope stages terminal 10 to early 8 (Bridgland 1994, Schreve et al. 2002). The sediments at Botany Pit consist of some 3.4 m of sand and gravel banked up against a Chalk river-cliff and are interpreted as the upper part of the complete Purfleet sequence seen in Bluelands and Greenlands Pits, dating to late stage 9/early stage 8 (i.e., > 300,000 years). Equivalent deposits in the neighbouring Greenlands Pit have provided an averaged age of 324,000 years by optically stimulated luminescence (Eddie Rhodes, personal communication).

The slightly rolled flint assemblage, recovered by Snelling in 1961 (Wymer 1968, 1985), is essentially a core-and-flake industry with few formal tools. Wymer (1968) described some of the cores from Botany Pit as proto-Levallois, and Roe (1981:228) too detected a much higher level of controlled flaking and considered some to represent a “reduced” Levallois method. Included in the Botany material are a small number of handaxes, recorded by Snelling as coming from the base of the Botany sequence and reportedly resting directly on Chalk. They probably predate the core-and-flake assemblage, and it seems likely that they are the final occurrence of the Acheulean industry represented in the Middle Gravel (the Bluelands Gravel of Schreve et al. 2002) in other pits from the area.

CORE TECHNOLOGY AT BOTANY PIT

The study of Lower and Middle Palaeolithic cores has undergone a dramatic shift in emphasis in the past 20 years (Boëda 1986, 1995; Chazan 1997; Ashton 1992, 1998), moving from an essentially typological approach (study of final form) to an explicit concern with tech-

nology (study of process). This is especially evident in the study of the Levallois method. Advocates and opponents of the two approaches are equally divided over several issues (cf. Boëda 1988, 1995; Dibble 1989; Van Peer 1992, 1995; Schlanger 1996), but the technological school has nevertheless succeeded in identifying a set of clear and replicable criteria for recognizing the Levallois concept that potentially avoids the major interanalyst variation and ambiguity that plague the typological approach (see Perpère 1986). It has also extended the boundaries of Levallois technology to subsume far greater variation than previously recognized (see Boëda 1986, 1995; Boëda, Geneste, and Meignen 1990; Chazan 1997). A technological approach is adopted here.

A total of 268 cores from Botany Pit from the Snelling Collection at the British Museum were examined during the present study. The cores can be classified into three basic operational schemas, although there is undoubtedly a continuum of variation in the approach to each of them.

The largest category (49%) can be described as migrating-platform cores of the kind that typify Lower Palaeolithic technology in Europe. The working of these cores consists of one or more sequences of flaking (core episodes), each episode involving single, parallel, or, most often, alternate flaking (Ashton 1998). Knapping generally proceeds in a varied and organic fashion, with the evolving morphology of the core strongly influencing the location and character of each core episode. The resulting cores vary enormously in morphology and the degree of working, have a diverse range of platforms, and are frequently quite chunky. The intention behind this type of working appears to be the removal of medium-sized flakes, which, because of the predominant use of alternate flaking techniques (cf. Ashton 1992, 1998; Ashton and McNabb 1996), tends to operate in an invasive fashion by removing material from the body or volume of the core.

The second category (43%) consists of cores previously described as proto- or reduced Levallois and clearly differs from the above in both concept and form (figs. 2 and 3). Flaking has been directed at the removal of large flakes, mainly in parallel sequences from single or adjacent platforms but sometimes in multiple or opposed directions. Rather than migrating around the core in pursuit of appropriate angles wherever they emerge, flaking is more controlled and is organized around a plane of intersection that defines a striking-platform surface and a flaking surface. Flakes are detached more or less parallel to this plane and remove material from the *surface* of the nodule rather than from its volume. Typically these cores show almost no preparation of either the flaking surface or the striking-platform surface. The striking platform was often simply created using one or more bold removals and then a series of flakes was removed from that platform, often along the long axis of the nodule. The resultant cores are generally flat, and the negative scars testify to the production of elongated flakes. Where more than one platform has been exploited, the same methods are repeated on other parts of

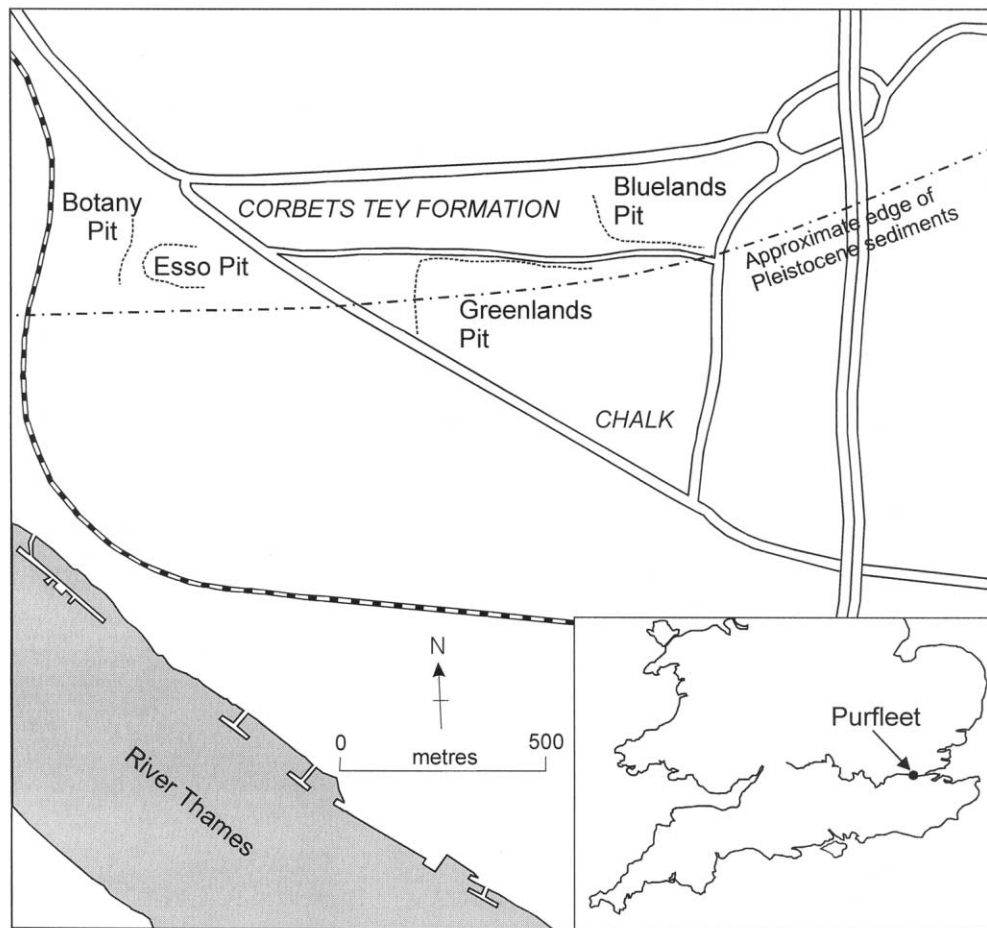


FIG. 1. Location map.

the core, and the relationship between flaking surface and striking-platform surface is preserved. In these cases, flaking from one platform dominates, but this is not necessarily the last platform created. The number of removals from each platform is difficult to gauge, although the evidence from the cores shows that two or three flakes per platform can be considered a minimum. As part of this group, 8% of the assemblage mimic classic Levallois by showing a final preferential removal. In most cases the final configuration of the core depends entirely on the removal of a large final flake from an otherwise non-Levallois core. However, two cores do display the features of classic tortoise-cores and may be quite deliberate.

The third category of core (8%) would generally be described as discoidal (Boëda 1995). Reduction was aimed at the removal of a series of flakes detached centripetally from two flaking surfaces situated above and below a plane of intersection. The surfaces are nonhierarchically organized, acting as both a flaking surface and a striking-platform surface, and the plane of intersection defines a hinge that extends around the perimeter of the core and

around which knapping takes place. While these differ from both the other core types in form and conception (see Boëda 1995), the distinction is not always technologically or typologically clear, and in some cases the final form may be a fortuitous result of another reduction strategy.

Although three methods of core reduction have been identified, it has proved difficult to distinguish characteristic flakes that result from each flaking method. There are more than 3,500 flakes from Botany Pit, and most of them display between two and four dorsal flake scars that tend to originate from a proximal or sometimes lateral direction. The butts are usually plain, occasionally dihedral, and never faceted. One would expect flakes resulting from the simple prepared cores to be slightly larger and slightly longer than those produced by other techniques, and large laminar flakes do exist within the collection. In practice, however, and in the absence of refits, it would be unwise to identify all of these as coming from such cores, especially given the probable mixed nature of the assemblage. As few diagnostic flake types seem to emerge from this type of core reduction, we

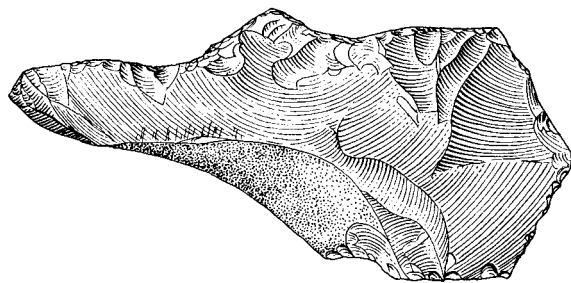
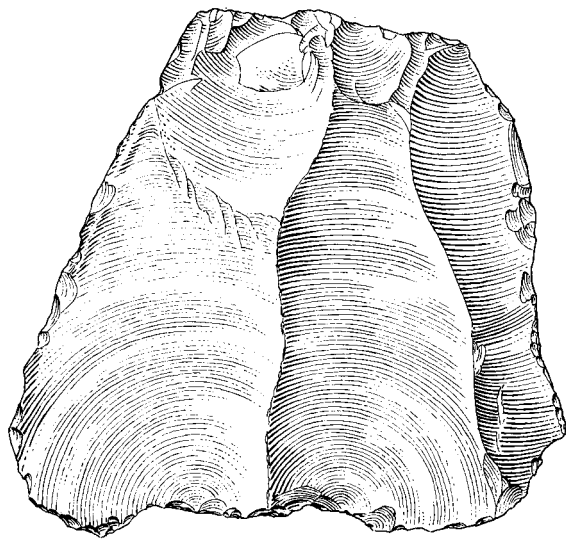


FIG. 2. Simple prepared core (proto-Levallois) from Purfleet.

suspect that the purpose of this technique was not so much to determine the precise form of the flakes as to control the volume and thereby the productivity of the core, producing a greater number of larger flakes from each nodule.

An indication of the type of flake that results purely from simple prepared cores can be found at the site of Frindsbury, Kent (Cook and Killick 1924). This poorly dated site produced an assemblage in fresh condition from a hollow within chalky drift directly above Chalk. Here, 14 of the 16 cores are of the simple prepared type, and they are associated with 478 flakes and 2 handaxes. The cores are identical to those from Purfleet, with the clear intention of flaking across surfaces, again from one or more platforms. As this is the dominant reduction method, the flakes clearly result from this type of flaking and, while falling into the range of variation seen within the amassed Purfleet sample, are distinguished by their comparative elongation and the predominance of a uni-linear flake scar pattern. This is illustrated by a group

of five refitting flakes (fig. 4), all knapped from the single, plain platform and presenting no evidence of preparation on the flaking surface. This type of flake certainly occurs as part of the Purfleet assemblage.

The refitting, fresh condition, and context (Cook and Killick 1924) suggest that the Frindsbury assemblage represents a relatively short phase of activity and reveals a narrowly defined set of core reduction practices. In contrast, the more complex stratigraphic situation at Purfleet, together with the greater and more variable condition of the artefacts, suggests the intermixture of several assemblages, which may explain the wider variety of core reduction strategies evident.

IS THERE LEVALLOIS TECHNOLOGY AT BOTANY PIT?

Previous descriptions of the Purfleet simple prepared cores have emphasized their similarities to Levallois cores (Wymer 1968, Roe 1981). The key question here is whether they can be considered to conform technologically to the Levallois concept *sensu* Boëda (1986, 1995; cf. Chazan 1997). Boëda has identified a limited number

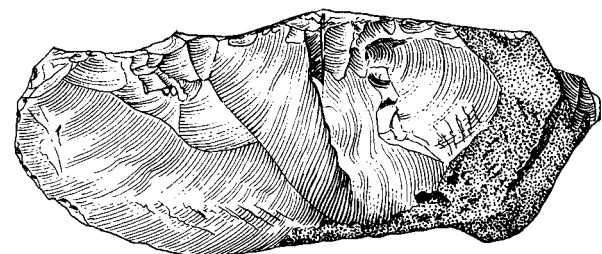
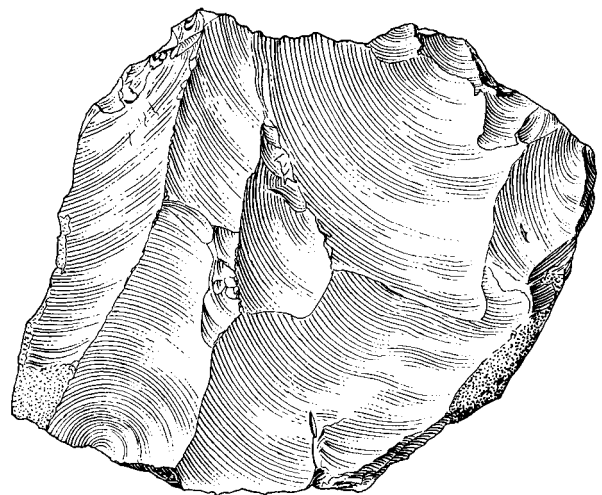


FIG. 3. Simple prepared core (proto-Levallois) from Purfleet.

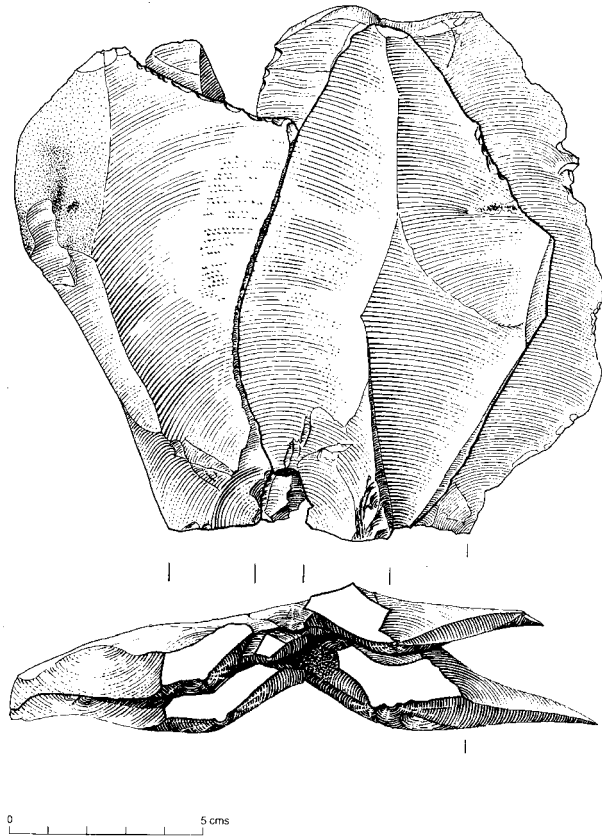


FIG. 4. Group of refitting flakes from a "proto-Levallois" core from Frindsbury, Kent.

of technical and geometric principles that underwrite all Levallois production (fig. 5). These principles are *absolutely constant*, but the manner in which they are executed and the initialization phase may vary, thus producing the range of variation now evident within Levallois technology. The simple prepared cores from Purfleet certainly conform to the Levallois concept in a number of important respects. The volume of the piece is conceived as two surfaces separated by a plane of intersection (criterion 1), and these surfaces are hierarchically related, one being a striking platform surface and the other a flaking surface (criterion 2). The fracture plane for the removal is broadly parallel to the plane of intersection (criterion 4), and the junction between the flaking surface and the striking platform (the hinge) is perpendicular to the axis of percussion and oriented to allow the removal of flakes from the flaking surface (criterion 5). Flaking is also exclusively done with a hard hammer (criterion 6). However, the Purfleet conception also differs from the strict Levallois concept in several respects. Most important, the flaking surface does not show the maintenance of distal and lateral convexities (criterion 3), and the preparation of either surface is minimal. Overall, the cores appear technologically under-

developed and procedurally truncated, especially when compared with classic Levallois cores. The core and its products are certainly under some control, and reduction is clearly geared towards removing large flakes from a surface rather than a volume (Boëda 1995), controlling the size of the product and the productivity of the core. Still, they do *not* appear to conform strictly to the Levallois concept.

If one or more of the underwriting principles is absent, can the technology still be considered Levallois? The same question was asked by Kuhn (1995) in his analyses of Pontinian Middle Palaeolithic assemblages from the Latium coast of Italy. Kuhn provided details of "prepared platform cores" that fulfilled some criteria of the Levallois concept but not others; like the Purfleet simple prepared cores they did not maintain distal and lateral convexities of the flaking surface (criterion 3) and had only limited core preparation and weak predetermination. Kuhn suggested that this might be a Levallois strategy stripped down to its essentials (i.e., two hierarchically related surfaces separated by a plane of intersection) to exploit the natural convexities of diminutive pebble blanks. This may be similar to the case of the stage 5/4 site of Saint-Vaast-la-Hougue, France (Guette 2002) where, using poor-quality beach pebbles, the convexities of the cores were minimally maintained but flakes were removed with clear platform alteration and preparation.

In contrast, Chazan (1997:732) suggests that because criterion 3 requires only that the two faces be organized in terms of convexities, not that they be shaped into such, then Kuhn's material, perhaps that of Saint-Vaast-la-Hougue, and by implication the Botany material are Levallois products. However, as far as we can see, organizing two convexities is tantamount to shaping.

It is shaping that immediately leads into the issue of predetermination or intentionality. Although this concept is popularly perceived to be inherent in the Levallois strategy, it has been disputed by some writers, particularly in questioning the Levallois method as a means of producing "privileged flakes." Davidson (2002) uses Van Peer's refitting work, which showed that many preparatory flakes were absent from knapping floors at several sites in Egypt, suggesting that Levallois flakes were not necessarily the desired end product. By contrast, many "final flakes" were simply abandoned at the knapping site. However, Van Peer (1992:114) provides several reasons that the Levallois strategy is an intentional act designed to produce large flakes (not necessarily of uniform shape and size). The strongest arguments are the abandonment of perfectly good cores after the production of a "last" large flake and, conversely, the repetition in flaking arrangement in instances where cores are reprepared to provide more than one such flake. He also cites examples from Nazlet Safaha 1 in Upper Egypt which contain a number of preparatory elements but no Levallois cores and flakes, the inference being that the preparatory and final stages have occurred in different parts of the site or elsewhere. He also warns against uncritically equating missing elements with human agency rather than excavation or refitting biases. In essence, the pro-

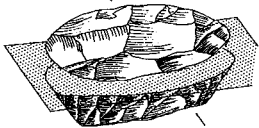

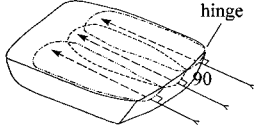
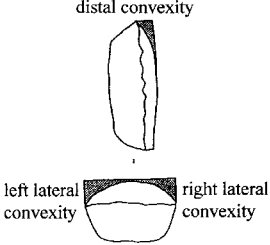

<p>Criterion 1: The volume of the core is conceived as two surfaces separated by a plane of intersection</p>	 <p>Criterion 4: The fracture plane for the removal of predetermined blanks is parallel to plane of intersection</p> 
<p>Criterion 2: The two surfaces are hierarchically related and non-interchangeable, one being a dedicated surface of striking platforms, the other a dedicated flaking surface</p>	<p>Criterion 5: The line created by the intersection of the striking platform surface and the flaking surface (the hinge) is perpendicular to the flaking axis of the predetermined blanks</p> 
<p>Criterion 3: The flaking surface is configured in a fashion that predetermines the morphology of the products. This predetermination is controlled by the management of lateral and distal convexities</p> 	<p>Criterion 6: Hard-hammer percussion</p> 

FIG. 5. Boëda's technological criteria for identifying the Levallois method (drawings modified after Boëda 1995).

duction of a large flake does not automatically reduce all other flakes to unwanted waste, and, while we might expect Neanderthals to have selected a range of flakes for future use, depending on need and context, this does not mean that the final large flake was unintended and unwanted.

Dibble (1989) takes a slightly different line, using a technological analysis of flakes from five sites in southern France to cast doubt on the degree of predetermination present in Levallois products. His data demonstrate that Levallois products are just as variable in terms of shape and size as non-Levallois flakes and handaxe thinning flakes, leading him to conclude that the Levallois method is a reductive strategy designed to extract many serviceable flakes from a single core rather than a single desired end product.

Chazan (1997:727) provides a neat précis of the current situation, suggesting that we do not know what the expectations of the knapper were in terms of predetermined flakes and by-products but we can surmise that the entire project of knapping was carried out with a specific plan of action and some knowledge of the end product. Our analysis and, we would suggest, that of Van Peer and Boëda are consistent with this conclusion.

In the case of Purfleet, then, there is a degree of intentionality in the sense of a specific plan of action designed to produce a series of large flakes but not predetermination through the shaping of the surface of cores (criterion 3) to produce one or more privileged or standardized flakes. We are therefore left with a number of

options. We could insist that the Purfleet simple prepared cores are merely stripped-down Levallois cores (as with the Pontinian?) stimulated by particular ecological, economic, or other local social factors. In this case what we see at Purfleet is stripped-down variations on lineal Levallois as well as unidirectional and bidirectional recurrent Levallois. While this conclusion might be acceptable within the limits of the already expanding Levallois concept, it would really only serve to defy attempts to study the Lower-to-Middle Palaeolithic transition and render the identification of a proto-stage impossible. Furthermore, in contrast to the Pontinian example, there are no obvious reasons here for a stripped-down Levallois technology to have been used. Raw material was probably abundant at the site, as the river was actively eroding the Chalk river cliff, and there are no obvious differences in raw materials between the core types described above. From residual cortex on the cores it would seem that the original nodules were medium-sized to large (20–25 cm) and not particularly flat, so this cannot be the reason simple prepared-core technology was used. Equally, the cores were rarely used to exhaustion, so shortage of raw material would not appear to have contributed to reduction strategy; on the contrary, Wymer (1985) described the use of flint at Purfleet as extravagant, a factor which in itself might have elicited a less rigid approach in some cases but surely cannot explain the frequency of these cores in a single assemblage and their absence from equally flint-rich horizons elsewhere in the local area.

The age, position, and technological parsimony of the Purfleet simple prepared cores favour an alternative. The Purfleet cores can be seen to represent a proto-Levallois technology stemming from two very simple conceptual innovations in core reduction: the plane of intersection and hierarchically organized surfaces. These two factors dictate the configuration of the core, and it is from them that the level of control apparently exercised over the method of flaking, the core and its products, and the associated technological complex all emerge, without necessarily being fully developed Levallois technology (see Kuhn 1995).

A selection of other western European sites (far from exhaustive) broadly contemporary with or slightly younger than Purfleet displays a similar approach to core reduction and supports such a conclusion. The Drenthian (stage 8) site of Markkleberg, Germany (Baumann and Mania 1983, Svoboda 1989), contains a number of cores showing similar technology alongside a number of other Levallois methods. As at Purfleet, the poor stratigraphic resolution at this site may be responsible for such a mixture. Early prepared-core technology has also come from the site of Mesvin IV, associated with a cool, steppic fauna and attributed to the early Saalian (stage 8) (Cahen and Michel 1986), while at Argoeuves (Lower Terrace Complex of the Somme, stage 8) unidirectional and bidirectional techniques have been used to produce series of laminar blanks (Tuffreau 1982, 1995) similar to those from Purfleet and Frindsbury. Rolland (1995) has summarized a wealth of literature that hints at a proto-Levallois phase in La Micoque levels 3 and 4; electron spin resonance dates for the higher level 5 have provided minimum age estimates for levels 3 and 4 ranging from 241,000 to 288,000 years. Further claims have been made for the site of Korolevo, Ukraine, where proto-Levallois cores have been identified as coming from levels that have been thermoluminescence-dated earlier than $360,000 \pm 50,000$ ago (Adamenko and Gladiline 1988).

The best example, however, comes from Orgnac 3, France, which is dated to 350,000–300,000 years ago (Moncel and Combier 1992). Here the basal levels (7–6) show a variety of non-Levallois methods, including a hierarchically organized centripetal technique, with prepared-core technology first appearing as a numerically low “complementary method” in level 5b. In its earliest manifestation it is generally unipolar or bipolar, its overall configuration suggesting to the primary workers a method that was controlled but whose rules were “*not fully standardized*” (our emphasis). By levels 4a and 4b fully fledged and formalized Levallois technology is seen, with diversification in the method to include most of the variants identified by Boëda. What we seem to have at Orgnac 3, then, is the gradual emergence, diversification, and standardization of an evolving technological practice in Europe as an elaboration of methods already in place.

Taken together these show a persistent and distinct change in approach to core reduction in which, in contrast to much Lower Palaeolithic flaking, consideration is given to core surfaces and volume. Although the re-

sulting flakes are only weakly predetermined, there is a clear element of control over the evolving core and its products. From the sites listed above this key change seems to occur across Europe from about 300,000 years ago, with the full suite of variation visible by ca. 250,000–200,000 years ago. The technology at these very early sites, then, suggests that the emergence of the Levallois method in Europe was gradual, involving the initial reorganization and recombination of core technology to establish a basic level of controlled flaking, followed by refinement, elaboration, and diversification towards a full Levallois concept.

DISCUSSION

Stone tool technology can be divided into two overarching operational systems: systems of flaking (*débitage*), in which the aim of the action is primarily to divide a volume of material into smaller usable units (i.e., flakes), and systems of shaping (*façonnage*), in which reduction is primarily geared towards reducing a mass of material using a complex of interrelated flake scars so that the remaining volume takes a desired form (see Boëda, Geneste, and Meignen 1990; Baumler 1995). In the first system the core—the nucleus of the nodule—is essentially waste and flakes are the desired result, while in the second system the situation is reversed.

In the Lower Palaeolithic, these two systems are essentially separate, operating according to different conceptual principles and for different purposes. The ambiguous “chopper-cores” notwithstanding, *façonnage* is predominantly manifest as bifaces, based around a plane of intersection separating two interdependent surfaces that may be hierarchical or non-hierarchical, biconvex or plano-convex, depending on the precise operational chain and blank type used (Boëda, Geneste, and Meignen 1990). There is no distinction between predetermining and predetermined flake removals, but the important point is that the two surfaces are organized in relation to each other. Reduction is oriented towards the removal of flakes from the surface of the piece so as to thin and shape an inner volume. Some question remains about the status of handaxes made on flakes, which for Boëda et al. represent examples of *débitage*. In contrast, we see the initial act of *débitage* (i.e., striking the flake blank) as being followed by the shaping of an internal volume to fulfil a mental construct, indicating to us that the last phase in the production and end result of action is actually *façonnage*. Whether or not this is conceptually correct, the most important issue here is that the two procedures are separate sequential steps in the biography of the object; the technology is non-reflexive.

Similarly, Lower Palaeolithic *débitage*, prior to oxygen isotope stage 9/8 (in Britain at least), is most often operationalized according to the migrating-platform concept. This is the simplest way of working a core, showing many varied and interchangeable platforms, no fixed plane of intersection, no hierarchically organized surfaces, little control over flake dimensions, and the working of a volume rather than a surface. Only the much

rarer discoidal or centripetal cores deviate from this general pattern, having a plane of intersection separating flaking and striking surfaces, although to what extent these are fortuitous rather than a product of blank shape is debatable (see, e.g., Orgnac 3, where centripetal cores are common but are produced on flint plaquettes—a case of blanks' dictating a technique or blanks' being selected to facilitate a technique?).

The differences evident in the Purfleet and other simple prepared cores can be described in these terms: as an elaboration of *débitage* brought about by the systematic application of concepts (i.e., plane of intersection and hierarchical interdependent surfaces) that had previously been most common, if not quite unique, to *façonnage* (White and Pettitt 1995). Rather than evolving directly from handaxes (Rolland 1995, Tuffreau 1995) or arriving fully formed courtesy of immigrant African hominids (Foley and Lahr 1997), both of which would demand no proto-phase, prepared core technologies originated *in situ* within north-western Europe (at least) through a gradual transformation of existing core technologies and a fusion of elements of both *façonnage* and *débitage*. In short, the development of the full Levallois concept represents for us the erosion of boundaries between and the integration of two existing systems, the practical fusion of *façonnage* and *débitage* into a new dynamic. While the final purpose was undoubtedly the production of select flakes, in our view it cannot be considered exclusively in terms of *débitage*, as it contains an elaborate shaping phase clearly aimed at controlling the form of an inner volume. But neither is it a system of *façonnage*, as the shaping of the core is only a means to producing desired flake blanks. In the Levallois method the core is involved in a reflexive interplay of these two concepts, constantly morphing from structured shaping phases to production phases; the rigid distinction between operational schemas seen earlier collapses and constructs that had been conceptually separate merge into one unified and highly flexible concept. That the products of early Levallois technology were used unmodified and to produce both scrapers and handaxes (with minimal modification) and that, in the wake of its emergence, handaxes tended to phase out in some regions serves to demonstrate the nature of this fusion and fundamental restructuring of technology. However, standard systems of *façonnage* and *débitage* do not disappear as redundant technologies but continue to exist alongside Levallois technology at various temporal and spatial scales.

If our reading of the Purfleet materials and its implications are valid, then there is an *in situ* evolution of Levallois technology in Europe via at least one proto-stage. This evolution parallels but is unrelated to the trajectories documented for Africa (Rolland 1995), where stochastically occurring examples of prepared-core technologies may extend back into the Lower Pleistocene, although Vermeersch's (1995) survey of the Northern African evidence failed to find any Levallois technology older than or even as old as that found in Europe. Given that a small and fairly simple mutation of technologies that had existed since the beginning of the Acheulean/

Developed Oldowan is required for prepared-core technologies to emerge, we must entertain the notion of many unrelated, polyphyletic "origins" of the Levallois method at different times in different places and in different ways (see Bordes 1971, Rolland 1995). In other words, Levallois is immanent within the Acheulean.

The Near East is a case in point, for here cores falling into categories of "proto-Levallois" and "flat débitage" are evident perhaps as early as 560,000 years ago (Copeland and Hours 1993), with a few of the latter somewhat resembling the Purfleet cores. By the Late Acheulean, non-Levallois flat-debitage cores identical to the Purfleet materials are found at sites such as Azraq C-Spring, Jordan, tentatively dated to ca. 225,000 years ago (Copeland 1989, 1991, 1995). Equally, though, an emergence from handaxes has been proposed at Tabūn (Debono and Goran-Inbar 2001). This brings us back to the precocious European Levallois reported at Cagny La Garrenne (Tuffreau 1995), where broken handaxes were exapted into cores that because of their origins of course possess some of the characteristics of handaxes. Although they may therefore fortuitously resemble Levallois products, they still serve to reinforce the technical fluidity of *débitage* and *façonnage* within prepared-core technology. India provides a further example of its pedigree and diversity. At the Isampur Quarry in the Hunsgi Valley, Petraglia, Schuldenrein, and Korisettar (n.d.) describe "prepared" cores made on large boulders worked around their perimeters, designed, they argue, to produce a large flake suitable for supporting a side-struck cleaver. Moreover, in the Malaprabha Valley these researchers have described "transitional" assemblages that show an unbroken flow from Lower Palaeolithic to Middle Palaeolithic technology. The shift is gradual, indicating that prepared cores have their roots in the local late Acheulean and that the transition from the Lower Palaeolithic to the Middle Palaeolithic is a gradual one.

Like most transitions, then, the emergence of prepared-core technologies was probably a matter of short bursts of frenzied innovation and variation with frequent "failures" and the eventual sedimentation and stasis of a successful form (Gould 1989, Goren-Inbar and Belfer-Cohen 1998). While the above examples nicely demonstrate that Levallois technology is immanent in Acheulean knapping practices, they also call into question the idea that it always emerged directly from handaxe manufacture as is widely presumed. The link lies in the principles and concepts underlying tool manufacture, not necessarily in the tools themselves; it is perhaps no surprise, then, that in areas that largely lacked these concepts (and by default show a paucity of the characteristic tools of the Acheulean, e.g., China [see Schick 1994]) Levallois technology never fully developed (Gao and Norton 2002).

The emergence of Levallois technology in Europe is not simply a restructuring of core technology. The transition may also be marked by other (diachronous) changes in technological practices. Although handaxes seem to be phased out in many areas as flake and flake

tool production increase (see Goren-Inbar and Belfer-Cohen 1998), in some areas they are retained at some level while in others (such as Germany) they actually increase dramatically. Moreover, those areas and phases that see the continued production of handaxes also seem to witness changes in their basic functions. The growing evidence from use-wear and site association suggests that handaxes in the Lower Palaeolithic are predominantly butchery tools (Keeley 1980, Villa 1990, Mitchell 1995, Austin et al. 1999). The overall aim seems to be the production of sharp-edged, symmetrical cutting tools, where the edge and the volume of the piece form a unified whole (Ashton and White 2001). In contrast, it has been suggested by Boëda, Geneste, and Meignen (1990) and J. Gouédo (personal communication) that Middle Palaeolithic bifaces should be understood through the distinct concepts of volumetric shape (encompassing the prehensile qualities of the tool) and the specific functional edges of the tool. They argue that in some industries (e.g., the Micoquian) bifaces had become the support for other tools, contained different functional areas on different edges of the same piece, and were the subject of resharpening. This flexibility in function has also been noted by Turq (2000:207–11) and Soressi and Hays (2001) on Middle Palaeolithic bifaces from France, where edges that serve as scrapers and notches are imposed on bifaces or bifaces are converted into cores. As with the Levallois method, there seems to be a breakdown of the distinctions between *façonnage* and *debitage*, with tools once produced from *debitage* now being produced as part of *façonnage*. As a result, technology becomes more flexible.

The changes in lithic technology are accompanied by a suite of wider changes related to the overall process of Neanderthalization. The lithic *chaîne opératoire* is arguably extended in time and space, involving greater mobility and higher levels of curation, with Levallois products being notably “mobile” (Geneste 1985, 1989; Féblot-Augustins 1999). Geneste (1985, 1989) had demonstrated that in south-western France Levallois products often occur on raw materials showing longer transport distances, testifying to a greater degree of curation for this technology. This has led White and Pettitt (1995) to argue that the Levallois was specifically a technology geared towards greater mobility. These patterns are partly reflected in the overall distances of lithic transfers in the Middle Palaeolithic (Roebroeks, Kolen, and Ren-sink 1988), with distances of up to 120 km in western Europe and up to 300 km in eastern Europe. While the general distribution and patterns of lithic transport in the Lower Palaeolithic and the early Middle Palaeolithic are comparable, suggesting behavioural continuity (with greater differences existing between the early and late Middle Palaeolithic), they nevertheless show some evidence for a greater variety of movement and curation (Féblot-Augustins 1999). At the same time, from oxygen isotope stage 8/7 there seems to be progressive adaptation of humans to more open and at times cooler conditions, in particular the rich semi-arid environments of the mammoth steppe (Ashton and Lewis 2002, Ashton

n.d.; cf. Guthrie 1990). One effect may have been a shift in settlement patterns, with human populations surviving better on the mammoth steppes of the east in warmer phases, tracking the westward expansion of the steppic biomes as climate cooled, and retreating to southern refugia during glacial extremes. Furthermore, the distribution and movement of herds in the more open landscapes would have required greater mobility of human populations and new strategies for dealing with the exploitation of such resources. This is reflected in the faunal record, with specialization in hunting noted increasingly from stage 7 onward (Gaudzinski 1995, 1996, 1999; Scott 1986; Jaubert et al. 1990; Stiner 2002).

These shifts in hunting specialization, mobility, and settlement pattern were probably accompanied by changes in group organization and size (Ashton and Lewis 2002). Other than from the faunal record, changes in group size might also be recognizable at early Levallois sites. The richest sites tend to concentrate around sources of very abundant raw materials, and the very dense concentrations suggest either very frequent visits to key resources or exceptionally large gatherings. If the latter, then the origins of Levallois technology might be underwritten by changes in the way in which systems of flake production were used in the social sphere, perhaps becoming more critical to the construction of social life—a role some believe was previously dominated by handaxes (Kohn and Mithen 1999; cf. Gamble 1999). Such an explanation might well help explain the elaboration of simple prepared cores into full Levallois products and the eventual sidelining of the handaxe. Given the previous hundreds of thousands of years of stasis, in which innovation is muted and rarely sedimented, all of this must be underwritten by changes in the mechanisms of social transmission (see Mithen 1994) and the power of agents to bring about lasting change in cultural structures (Hopkinson and White n.d.). Taken together, these show that the emergence of Levallois technology does not signal a simple technical shift to be explained in a monocausal fashion but is the lithic incarnation of a multifaceted transformation in human societies and their organization at this time that may herald the evolution of the Neanderthals and their modes of action.

CONCLUSION

The simple prepared cores from Purfleet represent a proto-Levallois technology dating to oxygen isotope stage 9/8. The cores demonstrate the employment of hierarchically organized surfaces separated by a plane of intersection and a volumetric core concept. This represents an innovative conceptual leap whereby principles previously limited to systems of *façonnage* are exapted to systems of *debitage*, presaging the development of the more sophisticated and finely controlled Levallois methods of the later Middle Palaeolithic. For us it is this *incorporation of difference* (Hopkinson 2001), the fusion of principles taken from two distinct operational systems, that characterizes the Middle Palaeolithic technology, leading to far greater variation and flexibility in

both core reduction and tool production than that witnessed in the Lower Palaeolithic. This is not necessarily the only route to Levallois technology, but it is one that may have had many different expressions before finally becoming integrated into the variety of techniques now recognized. Most important, the examples cited give a strong impression of continuity rather than abrupt change in technical practices in Europe and a suite of associated changes that are progressive rather than abrupt. This does not, of course, refute Foley and Lahr's suggestion of an exclusive African origin, but it leads us to question the arrival in Europe of a fully developed system in the hands of a group of dispersing hominids equipped with the skill and knowledge to practice it. It is, however, interesting to note that when it finally takes hold the Levallois method appears to occur almost simultaneously across Europe, the Near East, and Africa. This may well be a problem with the resolution of our dating, which through time averaging often contemporizes events that are in reality separated by tens of thousands of years, but if real it shows that even if hominids were not moving, ideas and techniques were being transmitted through extensive social networks of the supposedly small and isolated human populations. The origins of Levallois technology and the changes that accompanied it have remained a neglected area of research that has cognitive, behavioural, and social implications and clearly warrants a global program of multidisciplinary investigation.

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