Evolutionary Anthropology 14:186–198 (2005)

Innovation and Technological Knowledge in the Upper Paleolithic of Northern Eurasia

JOHN F. HOFFECKER

The technology of modern humans is unique in the animal kingdom with respect to its complexity and capacity for innovation. Evidence of technological complexity and creativity in the archeological record is broadly coincident with and presumably related to traces of creativity in art, music, ritual, and other forms of symbolism. The pattern of modern human technology is part of a larger package of behavior (sometimes referred to as "behavioral modernity") that emerges with the appearance of industries in Eurasia classified as Upper Paleolithic, but has deeper roots in the African Middle Stone Age.[1–5]

Before the Upper Paleolithic and the later Middle Stone Age, evidence of technological change in the archeological record is comparatively limited. Some of this may be a consequence of the almost complete lack of preserved materials such as wood, plant fibers, and hide, but commonly preserved artifacts of stone exhibit no significant change over intervals of hundreds of thousands of years. Moreover, when a new mode of technology (for example, bifacial tools) appears, it is often associated with the emergence of a new form of *Homo*.[6] It is only with the advent of Upper Paleolithic industries produced by modern humans that spatial and temporal variation in technology reaches a level commensurate with that of recent and living peoples and indicates a fundamentally similar capacity for innovation, defined broadly in this context to include invention, improvements to existing technology, and the application of both.[7]

Despite the fact that the Upper Paleolithic, with a time span of more than 30,000 years, represents the longest interval of technological creativity in modern human prehistory and history, it has been all but ignored by students of innovation. Most such students are historians or economists, who are unfamiliar with the methods and data of archeology, especially the archeology of prehistoric foraging peoples. They have tended to view the Upper Paleolithic as an extension of the Lower and Middle Paleolithic—a period of slow and limited change in the basic equipment of hunter-gatherers.[8,9]

It has become increasingly apparent, however, that the Upper Paleolithic was a period of almost constant technological change not unlike the last 12,000 years. Peoples of the Upper Paleolithic invented sewn clothing, portable lamps, and watercraft. They also designed heated shelters, fishing equipment, baking ovens, refrigerated storage pits, and artificial memory systems. Upper Paleolithic folk used rotary drills, shaped musical instruments, mixed chemical compounds, and constructed kilns to fire ceramics. They were the first to create mechanical devices, including spear-throwers and bows and arrows, and to domesticate another living species.

Archeologists, of course, have always viewed technology as a topic of central concern. In the nineteenth century, the study of prehistory was built on a sequence of stages in the progressive evolution of technology.[10] But archeologists have rarely addressed questions about the pattern and context of innovations, the sort of questions that historians of technology ask about the invention of clocks, printing presses, and steam engines.[11–13] Where and when did major technological innovations take place during the Upper Paleolithic? Were these innovations isolated, seemingly random events, or did they appear in clusters? Did they represent primarily new inventions (radical or discontinuous innovations)[7] or incremental improvements on existing technologies (continuous innovations)? Did they arise in the context of larger settlements and social networks or in smaller group settings? Were technological innovations associated with changes in climate and the effects of these changes on landscape and biota?

Technology is a form of knowledge about the environment or, as Martin Heidegger wrote, "a way of revealing" the world.[14,15] Although some technologies have been abandoned or rejected by societies,[16] the general trend has been cumulative growth of technological knowledge.[9,12,17,18] Historians of technology and some philosophers and anthropologists have

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Key words: modern humans; technology; innovation; Upper Paleolithic; northern Eurasia

DOI 10.1002/evan.20066
Published online in Wiley InterScience (www.interscience.wiley.com). y

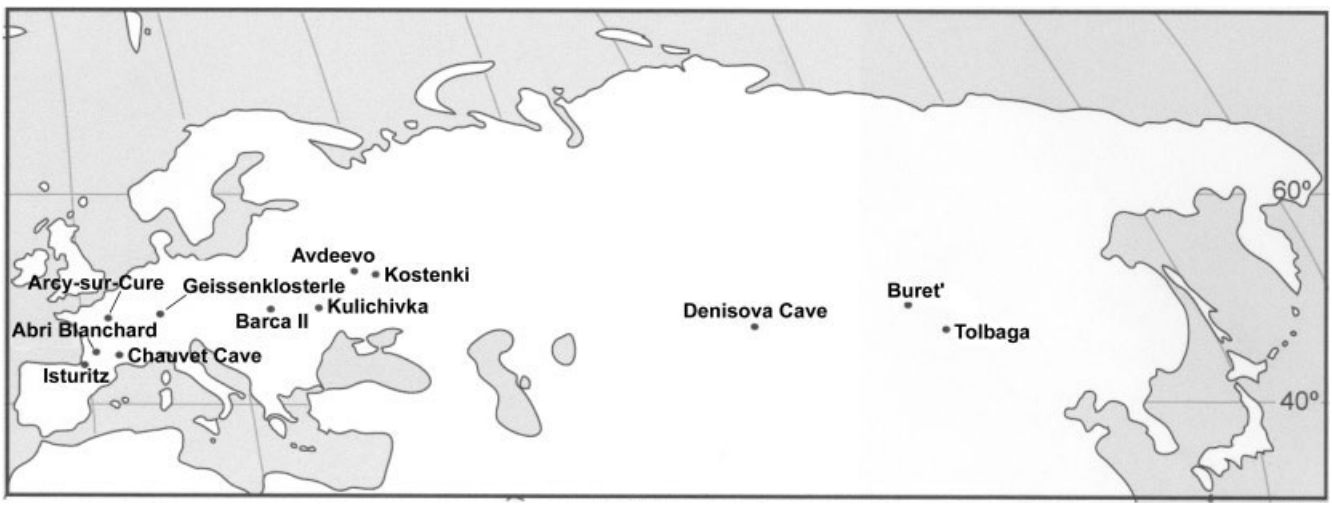

Figure 1. Map of northern Eurasia illustrating the locations of early Upper Paleolithic sites mentioned in the text.

emphasized the connections between technology and both social organization and world-view.[19–24] Such connections are apparent in tribal societies and prehistoric contexts.[15,25–27] To what extent did innovations during the Upper Paleolithic build on existing technologies and produce cumulative growth of technological knowledge? And did these innovations occur in conjunction with major changes in art, ritual, and other expressions of world-view?

Archeologists have been slow to appreciate the scope and significance of technological innovation in the Upper Paleolithic for several reasons. There has been a longstanding focus on widely recovered items, primarily stone artifacts, that serve as diagnostic markers of classificatory units such as Aurignacian, but that comprise a very limited spectrum of Upper Paleolithic technology. Many of the more novel implements and devices were almost certainly constructed from wood, fiber, bone, antler, and other materials that do not preserve as well or only in exceptional circumstances.

Most major Upper Paleolithic innovations possess low visibility in the archeological record and some, such as domesticated dogs and cooking ovens, have come to light only in recent years.[28,29] Late prehistoric middens of the arctic coastal zone often contain small fragments of modified bone, ivory, wood, or other material; these fragments are isolated but identifiable components of complex technology such as bows and dogsleds.[30,31] Although a comparable ethnographic context is lacking, careful analysis of similar items in Upper Paleolithic sites may also reveal traces of such technology.

This paper is intended to provide a concise overview of innovation and the accumulation of technological knowledge in the Upper Paleolithic of northern Eurasia. While important innovations occurred in the lower latitudes, Upper Paleolithic sites above 40° North, which offer a more manageable subset of the global database, are the primary focus. The overview is designed to explore briefly the broad patterns of innovation and their social, economic, and environmental context. Finally, it touches on a question raised recently outside northern Eurasia: To what extent did the accumulating technological knowledge of the Upper Paleolithic provide the necessary foundation for sedentism, agriculture, and urban life in the postglacial epoch?[32]

TECHNOLOGICAL INNOVATION IN THE EARLY UPPER PALEOLITHIC

The pattern of complexity and creativity in Upper Paleolithic technology is part a larger package of behavior that is represented in the archeological record by traces of ornament, engraving, sculpture, musical instruments, and other forms of symbolism. Additional elements of the package include long-distance movement of raw materials, increased standardization of artifacts, and more structured use of domestic space, all of which may be indirectly linked to symbolism. The whole complex is primarily associated with the evolution of modern humans (*Homo sapiens*) in Africa prior to 100 ka (100,000 years ago) and sometimes labeled "behavioral modernity."[3,4,33–34]

Whether behavioral modernity evolved gradually in Africa during 300 to 100 ka or rather suddenly at the end of this interval remains a matter of debate among paleoanthropologists.[3,35] Regardless of the process by which it became established among *Homo sapiens,* behavioral modernity appears, after 100 ka, to have reached a threshold that permitted modern humans to expand out of Africa and the Near East into a wide range of habitats across Eurasia and beyond.[36–38] The organizational flexibility that language and other forms of symbolism help to effect may have played a significant role in the dispersal, especially in arid environments where resources are scattered,[39,40] but the ability of behaviorally modern humans to create new and complex technologies was almost certainly of primary importance.

Artifact assemblages that may be assigned to the Upper Paleolithic are dated to as early as roughly 45 to 40 ka in parts of eastern Europe and south-

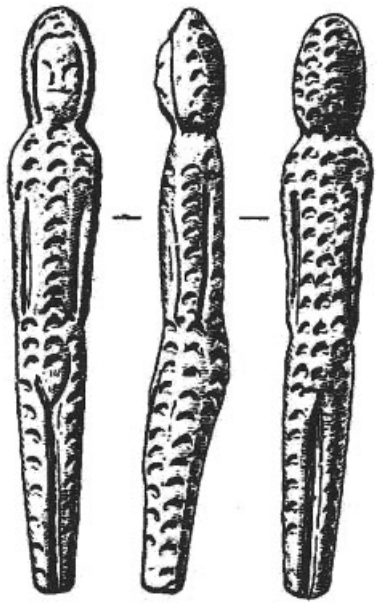

Figure 2. Figurine from Buret' (southern Siberia) confirming the existence of complete tailored fur suits with hoods by 24 ka. Eyed needles in older sites suggest that this technology may have been developed as early as 35 ka. (Redrawn from Medvedev 1998:225, Fig. 114).

ern Siberia (Fig. 1).[41,42] Human skeletal remains in northern Eurasia that can be firmly attributed to modern humans are several thousand years younger, and some of these have recently been redated to later periods.[43] However, it is widely assumed that modern humans produced at least some of the earlier assemblages.[44,45] The oldest Upper Paleolithic occupations in western Europe (Aurignacian industry) are younger (≤40 ka), and apparently represent delayed settlement of a region still heavily populated by Neanderthals (who seem to have been scarce or absent in many parts of eastern Europe and Siberia).[46,47]

Upper Paleolithic sites in northern Eurasia that antedate the demise of the last Neanderthals (ca. 30 ka) may be considered early Upper Paleolithic (EUP). These sites were occupied during later phases of the interstadial that correlates with Marine Isotope Stage 3. The EUP represents a protracted interval during which modern humans dispersed across northern Eurasia and established themselves as far as 55° to 56° North (and above the Arctic Circle at least on a seasonal basis).[48,49] The large and complex settlements that appear in some areas at the time of the middle and late Upper Paleolithic are lacking before 30 ka. The small size of many EUP sites, sometimes deeply buried, constrains the analysis of technological change during this interval.

The EUP yields evidence of many technological innovations that are absent in local Middle Paleolithic industries. Some of this technology seems to have been developed during the late Middle Stone Age (MSA) in Africa and presumably was imported to Eurasia by modern humans. At a minimum, this seems to include polished bone points and bone awls, as well as perforated shells, which are dated to 76 ± 5 ka in MSA levels at Blombos Cave (South Africa).[50,51] On the other hand, barbed harpoons of bone (Katanda, Zaire), which may date to 90 ka and are therefore tentatively assigned to the MSA,[52] are absent in the EUP. This technology does not appear in northern Eurasia until the later Upper Paleolithic.

Other innovations appear for the first time in EUP sites, and at least some of them are plausibly tied to the colonization of higher latitudes. Clothing and shelter technology were probably essential for *Homo sapiens* settlement of northern Eurasia, especially eastern Europe and Siberia, where winter temperatures 45 to 30 ka were lower than those of today.[53] The problem of adjusting to these climates was exacerbated for modern humans dispersing out of Africa by the retention, until late Upper Paleolithic times, of body dimensions better suited for the tropical zone,[54] while the pace of development in clothing and shelter technology may have been influenced by the succession of warmer and cooler oscillations that took place during the later phases of MIS 3 and the subsequent onset of the Last Glacial Maximum.[55]

Current archeological data suggest that tailored fur clothing was developed gradually in the north Eurasian Upper Paleolithic. Although carved figurines from the south Siberian site of Buret' dating to ca. 25 ka depict humans dressed in complete fur suits with snug-fitting hoods (Fig. 2),[56] occupation levels dating to more than 35 ka contain only bone awls (presumably derived from the African MSA). Indirect evidence of sewn clothing in the form of eyed needles is reported from Kostenki 15 on the East European Plain at ca. 35 to 30 ka.[57] Needles are also reported from Tolbaga (southeast of Lake Baikal) in deposits dated to 35 to 28 ka.[58] An eyed needle was recovered from Layer 11 of Denisova Cave (Altai region), which yielded a date of >40 ka, but it may be intrusive from a younger level.[59] Independent dating of tailored clothing may be provided by analysis of DNA sequences from a global sample of body lice, which inhabit modern human clothing, indicating an African origin at ca. 72 ka (±40 k).[60]

Tailored clothing is one of the most complex forms of technology among recent peoples of the Arctic,[61] and it is unfortunate that the EUP record does not yield more details about its design. If equipped with drawstrings, for example, it might have been the first mechanical technology. The presence of some form of line in the EUP is indicated by microwear on perforated ornaments.[62] Subsequent design improvements might have had a major impact on Upper Paleolithic settlement,[63] but they are invisible in the archeological record.

Traces of artificial shelters are also found in east European and south Siberian sites that probably were occupied by at least 30 ka. As in the case of tailored clothing, there is no convinc-

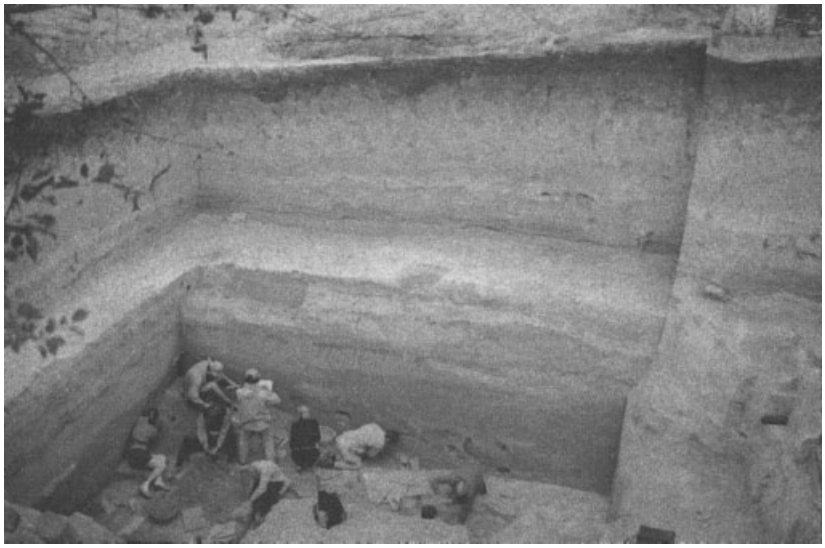

Figure 3. Excavations at Kostenki 14, one of a group of sites on the Don River in Russia that have contributed much information to the study of technology and innovation during the early and middle Upper Paleolithic. Early Upper Paleolithic occupation levels are often deeply buried and exposed over relatively small areas. (Photo by author).

ing evidence of artificial shelters in the Middle Paleolithic of northern Eurasia. They appear to have been another major innovation of the EUP. Traces of shelters with interior hearths lined with rocks are reported from Tolbaga, and also from a level at Kulichivka (western Ukraine) dating to ca. 30 ka.[58,64] They were oval in plan and surprisingly large (at least 5 to 6 meters in diameter). Although post-molds have not been detected, these hearths probably possessed a framework of wooden poles covered with hides. Former structures also may be present at several central European sites of comparable age, including Barca II, which exhibits post-molds (Slovakia).[65] The absence of evidence of artificial shelters in sites older than 30 ka may simply reflect their low archeological visibility due to the small sample of excavated floor area and the ephemeral character of the structures.

There is no evidence, direct or indirect, of the use of fire-making devices, but their existence is plausible for several reasons. A few recent hunter-gatherers were found to lack fire-making technology,[66,67] but none of them inhabited places where mean winter temperatures fell below the freezing point. Moreover, other lines of evidence indicate that the earliest EUP people in northern Eurasia had already developed the requisite technology in the form of a hand-operated rotary drill, deduced from microwear patterns on drilled stone from Kostenki 17.[62] Applied to a piece of dry wood with tinder (for example, wood meal), this is a simple and effective method of generating a flame.[68,69]

Much of the food consumed by EUP people in northern Eurasia was obtained from the same large mammals as were hunted by the Neanderthals, although the EUP people invented a new technique of hafting for spear points with a wedging mechanism in the form of a split-based antler point, found in sites of western and central Europe.[70] However, a large concentration of hare bones in the lowest levels of the open-air site at Kostenki 14 also indicates a significant expansion of food resources (Fig. 3).[71] In addition to hare, there is evidence that foxes and wolves were being harvested at Kostenki during this period, and procurement of these fur-bearing mammals is plausibly linked to the innovations in tailored clothing production. Equally significant is the stable-isotope analysis of human bone from Layer III at Kostenki 1 (>30 ka), indicating high consumption of freshwater aquatic foods (waterfowl and/or fish).[72]

The expansion of food resources was almost certainly achieved with the design of new technologies for catching or killing animals that were too elusive or inaccessible for Middle Paleolithic people.[73] The new technologies could have included traps, snares, nets, and throwing darts, although no direct evidence of any of them has been identified yet in the EUP. Traps and snares are "untended facilities" and reduce human labor costs. A survey of such devices among recent hunter-gatherers indicates a wide range of design complexity.[74] Presumably the earliest forms were of comparatively simple design (for example, the two-to-three-component snare).

One of the most interesting areas of innovation in the Upper Paleolithic is information technology. Some evidence of notation emerges from Aurignacian sites (for example, Abri Blanchard, France) as early as 35 to 30 ka in the form of bone and ivory fragments with rows of engraved marks. Marshack[75] interpreted some of these as lunar calendars similar to the calendar sticks found among various recent hunter-gatherers. Although this interpretation has been disputed,[76] scanning electron microscopic analysis of engraved pieces from various Upper Paleolithic time periods indicates that simple notation (or "artificial memory") systems are present in the EUP.[77,78]

More impressive are the technologies devised to create structures of light (visible colors) and sound in the form of paint and musical instruments. Direct accelerator mass spectrometry dating of the Chauvet Cave paintings, which represent two-dimensional images rendered with charcoal and hematite, indicates that they are EUP (ca. 35 ka).[79] Musical instruments have been recovered from EUP levels at two sites in western Europe, Geissenklosterle (Germany) and Isturitz (France).[80,81] Recently described as "pipes" (not "flutes"), these oldest known instruments of bone exhibit a remarkably sophisticated design.[78]

A major issue in Upper Paleolithic technology is the time and place of the first mechanical innovations.

YEARS BEFORE PRESENT	WESTERN EUROPE	CENTRAL EUROPE	EASTERN EUROPE	SOUTHERN SIBERIA
10,000				
	FISH HOOKS			
12,000	LEISTERS			
14,000	BOW & ARROW			HARPOONS
16.000	DOMESTICATED DOG			THROWING DARTS
	PAVED FLOORS	FISH HOOKS	TRAPS	
18,000	HARPOONS		DOMESTICATED DOGS	
20,000			BONE HOUSES	
	SPEARTHROWER			
22,000	BARBED POINTS			
	HANDLED LAMPS			
24,000	EYED NEEDLES			[HOODED SUITS]
			CORDAGE	
26,000		LIGNITE FUEL	FAT LAMPS	LIGNITE FUEL
		CORDAGE	COLD STORAGE	
28,000		FIRED CERAMICS	WINTER HOUSE	
		STORAGE PITS	MATTOCKS	
30,000		EYED NEEDLES		
32,000				
	LUNAR CALENDARS?		HEATED SHELTERS	HEATED SHELTERS
34,000	WIND INSTRUMENTS		SHOVELS	NEEDLES
	PAINT COMPOUNDS		EYED NEEDLES	
36,000				
38,000	SPLIT-BASE POINTS	SPLIT-BASE POINTS		
40,000	BONE AWLS		BONE POINTS	BONE AWLS
			SNARES?	BONE POINTS
42,000			ROTARY DRILL	
			FIRE-MAKING DRILL?	
44,000			BONE AWLS	

Figure 4. Major innovations of the Upper Paleolithic, showing their approximate spatial and temporal position on the basis of current archeological data.

The ability to design mechanical tools, weapons, and devices, specifically ones composed of moving parts, seems to be a defining difference between the technology of modern humans and all other animals.[38,82] Some EUP technologies, including tailored clothing, fire-making equipment, and possibly traps may have been at least partly mechanical. On the other hand, non-mechanical forms of these technologies or, indeed, alternative technologies, may have been used during this period. The oldest known mechanical technology is currently confined to the later Upper Paleolithic.

Although it is logical to assume that much EUP innovation in northern Eurasia represents modern human responses to higher latitudes (that is, to lower winter temperatures and reduced biotic productivity),[38] only some of this innovation can be documented in the earliest occupations (≥40 ka). Many early inventions, such as notation and musical instruments, probably were not critical to modern human survival in these latitudes. Other innovations, including some that would seem to have been essential at least during periods of cooler climate, such as artificial shelters and tailored clothing, apparently were developed several millennia after modern humans had arrived in Europe and Siberia (Fig. 4).

UPPER PALEOLITHIC TECHNOLOGY AND THE LAST GLACIAL MAXIMUM

The Upper Paleolithic of northern Eurasia can be subdivided into three phases broadly corresponding to major climate intervals. The early phase (45 to 30 ka) took place during the later part of the lengthy interstadial that is often referred to as the Middle Pleniglacial. The second phase (30 to 20 ka) spans the interval between the final millennia of the Middle Pleniglacial and the peak cold of the Last Glacial Maximum. The third phase (20 to 12 ka) began in the aftermath of the cold peak and

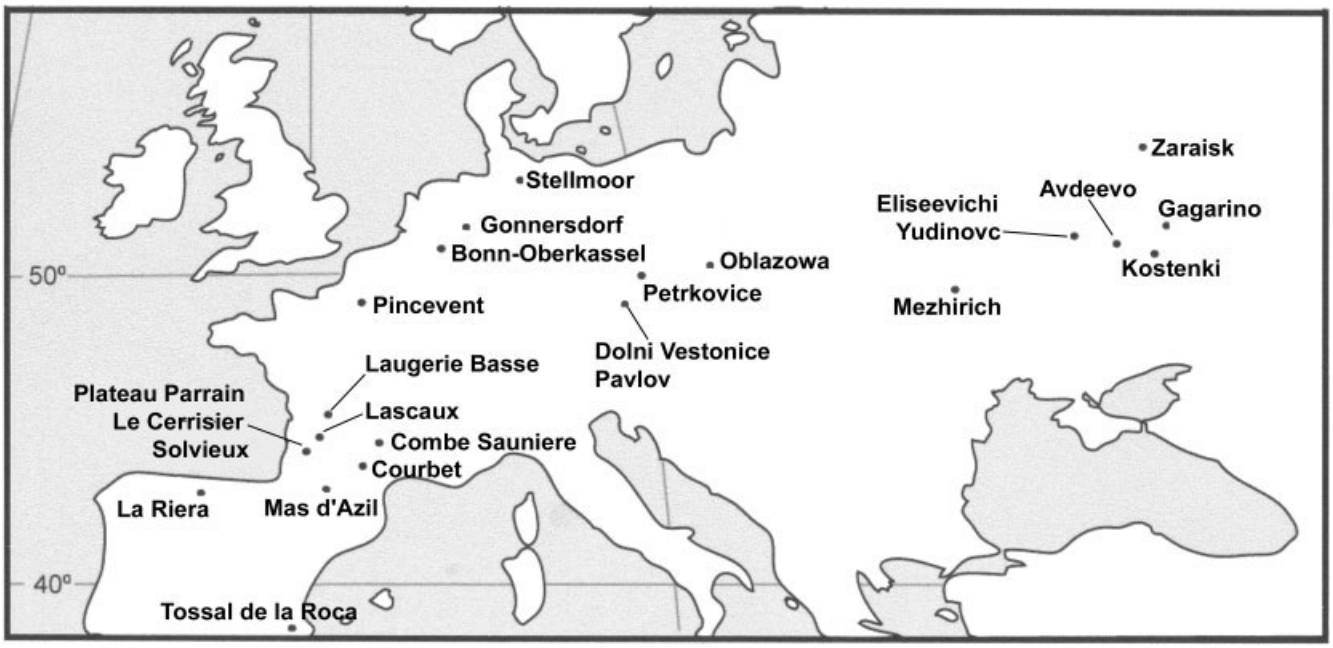

Figure 5. Map of Europe, illustrating the location of middle and late Upper Paleolithic sites mentioned in the text.

lasted until the end of the Late Glacial Interstadial.[44,83,84]

The second phase, or middle Upper Paleolithic (MUP), witnessed a new burst of innovation, much of which took place with the appearance and spread of the Gravettian technocomplex in Europe (Fig. 5). In contrast to the EUP, most of the innovations seem to have occurred within a comparatively brief span of time, and are linked to a characteristic array of art and ritual forms. Many of the sites are larger and more complex than EUP sites, probably indicating an increase in population and resource consumption. Although the Gravettian industry is not found outside Europe, at least some of the new technology is found in the MUP of Siberia.

The technological innovations of the Gravettian are sometimes attributed to the onset of cold climates at the end of the Middle Pleniglacial.[83] Because a significant correlation has been found between technological complexity and latitude among recent hunter-gatherers,[74] it is logical to assume that declining temperatures would have acted as a stimulus to technological change. At least some of the new Gravettian technology is clearly tied to periglacial environments. It should be noted, however, that a subsequent series of innovations, including some of the most impressive technical achievements of the Upper Paleolithic, took place after climates in northern Eurasia began to warm (that is, following the coldest phase of the Last Glacial Maximum).

Improvements in artificial shelter design are evident at Gagarino on the Don River (Russia), which yielded traces of what appears to be a semi-subterranean winter house dating to 25 ka (Fig. 6).[85] The apparent scarcity of wood in the area at this time encouraged use of alternative fuels, and the interior hearth was filled with burned bone, which requires some brushwood to generate sufficiently high ignition temperatures.[86] Portable lamps fashioned from the femoral heads of mammoths, presumably fueled with mammal fat, were found in the Gravettian level at Kostenki 1,[87] while the use of coal was reported some years ago at Petrkovice (Moravia).[88] Stone lamps are found in contemporaneous sites in western Europe.[89] Although it is not known if further improvements were made in tailored clothing design, the clothed figurines from Siberia mentioned earlier date to this interval, during which eyed needles also appeared in central Europe for the first time.[84,88] Eastern Gravettian sites such as Avdeevo, in Russia, have yielded isolated examples of needle cases similar to those of the Inuit.[85,90]

Many Gravettian sites contain large pits filled with bone and other debris. These represent the earliest known storage devices. They may have been used primarily during warmer months for cold storage of food or bone fuel, which must be kept fresh to retain flammability. The pits seem to have been dug to the base of the active thaw layer to create a naturally refrigerated chamber similar to the "ice cellars" of recent Arctic peoples. The digging implements, according to microwear analysis, included large mattocks of mammoth ivory, which have been recovered from Zaraisk (Russia)[91] and other Eastern Gravettian sites. These implements also exhibit parallels with Inuit technology.[90]

The Gravettians improved on early Upper Paleolithic hunting technology by designing beveled spear points that, in contrast to earlier hafted points, lacked a bulge at the base.[70] An ivory boomerang was found at Oblazowa (Poland).[92] Indeed, there may have been significant new developments in the technology of small-game procurement. Large quantities of small mammal remains and stable-

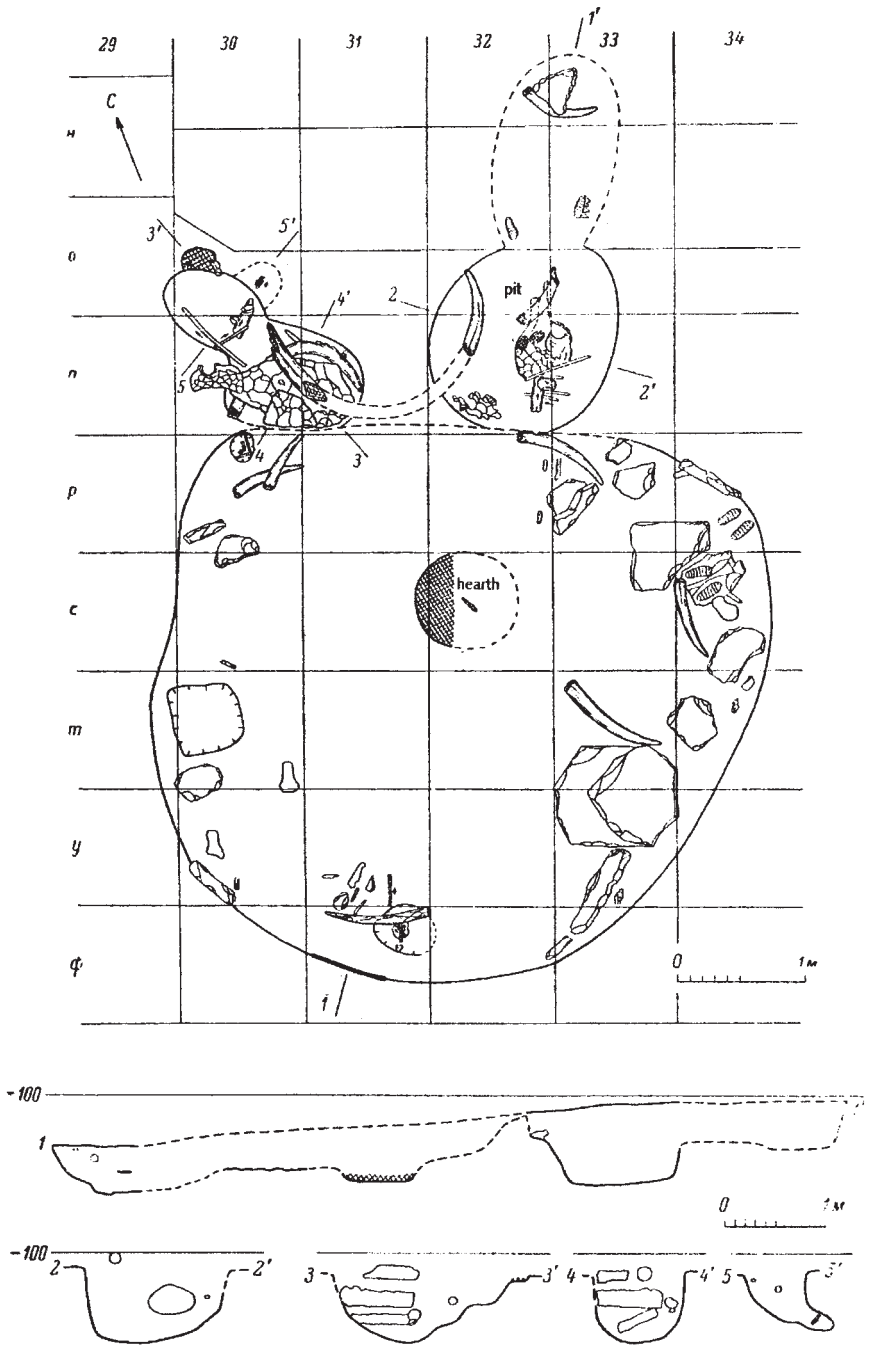

Figure 6. Plan of a semi-subterranean house, possibly occupied during winter months, excavated at Gagarino on the Don River in Russia. (Modified after Tarasov 1979:54, Fig. 27).

isotope data from human bone indicate that the Gravettians and their counterparts in southern Siberia consumed a broad array of terrestrial and freshwater foods.[72] Although nets were postulated as one possible means of obtaining small game during the EUP, they are documented in Gravettian sites for the first time, along with the major new technology of cordage.[88,93] Weaving and net-making implements of bone and ivory have been tentatively identified at several localities, including Pavlov I (Moravia) and Kostenki 4 (Russia).[94]

The most impressive Gravettian innovation was in the field of pyrotechnology. It is now clear that the fired clay objects recovered from their sites for many decades were not always haphazard creations, but at times were produced in specially designed kilns heated to 500 to 800°C (identified at Dolni Vestonice I, Moravia) (Fig. 7).[95] As is often the case with major innovations in modern human technology (for example, weight-driven clocks, originally designed for the timing of prayers[19]), its value can be defined only within the context of myth and ritual. The fired clay objects, chiefly figurines, had no identifiable utilitarian function.[96]

Some Gravettian sites in central and eastern Europe contain occupation floors of unprecedented size and complexity (for example, Kostenki 1) that apparently reflect at least temporary aggregations of large numbers of people.[90] These gatherings were presumably used to reinforce social ties, but they might have had some economic significance as well (for example, communal hunts).[88] It is the large sites that suggest that a major increase in population density and resource consumption had taken place during the MUP. This may have been primarily a consequence of the rich loess-steppe habitat that emerged in these regions after 28 ka,[84] which the Gravettians effectively exploited with technology inherited from the EUP as well as their own innovations.

Last Glacial Maximum climates reached their coldest phase at ca. 24 to 21 ka with severe effects on Upper Paleolithic settlement. Portions of northern Europe, the central East European Plain, and much of Siberia seem to have been abandoned at this time.[1,44,45] This may reflect the limitations of MUP technology for cold protection, but it might also be at least partly a function of the inherited warm-climate morphology still retained by the Gravettians.[38] People continued to occupy southwest Europe, although there is evidence of population stress and the appearance of a new local industry (the Solutrean).[97]

Several technological developments of the Solutrean are worth noting. For the first time, eyed needles and, by implication, sewn tailored clothing, were produced in western Europe.[83] It is not known whether this technology

Figure 7. Reconstructed kiln at Dolni Vestonice I (Moravia). (Redrawn from Soffer et al. 1993:271, Fig. 4B).

was invented locally or adopted from peoples in central and eastern Europe. Self-barbed points of antler, apparently designed for spearing fish, were used in some coastal sites, among them La Riera (Spain).[98] During the late Solutrean (ca. 21 ka), the first spear-throwers, which represent the first confirmed mechanical technology, appeared in the archeological record at, for example, Combe-Sauniere I (France) (Fig. 8).[99]

LATE UPPER PALEOLITHIC INNOVATION

In the wake of the Last Glacial Maximum cold peak (24 to 21 ka), peoples in many regions of northern Eurasia established long-term settlements supported by highly efficient technologies for harvesting and sometimes storing a wide array of food sources. The same pattern is evident even earlier in some lower latitude regions.[29] The technologies may have reached a critical threshold for the establishment of sedentary farming villages in the postglacial epoch.

Above latitude 40° North, eastern Europe contains the most impressive evidence of long-term settlements in the 18 to 14 ka interval (Epi-Gravettian): groups of up to four houses composed of mammoth bone and tusk. These occur at several sites, including Mezhirich (Ukraine) and Yudinovo (Russia).[100,101] The houses are circular or oval, at least 3.5 meters in diameter, and associated with deep storage pits and enormous quantities of occupation debris. Assuming that they were occupied simultaneously, which can be demonstrated in at least one case, the Epi-Gravettian "villages" probably represent encampments of 25 to 50 people for periods of several weeks and perhaps even several months (Fig. 9).[102]

Late Upper Paleolithic (LUP) sites in western Europe (Magdalenian), such as those at Pincevent (France) and Gonnersdorf (Germany) also contain traces of multiple structures.[103,104] These include sites with the remains of rectangular structures up to 4 × 6 meters in area marked by rock pavement floors as at, for example, Plateau Parrain and Le Cerisier (France).[105] At Solvieux (France), the structures contain handled lamps and are associated with possible stone boiling pits.[106] By contrast, the Siberian sites appear to represent small short-term occupations, probably reflecting a significantly less productive habitat.[38,44]

The innovative use of bone and rock for constructing the walls and floors

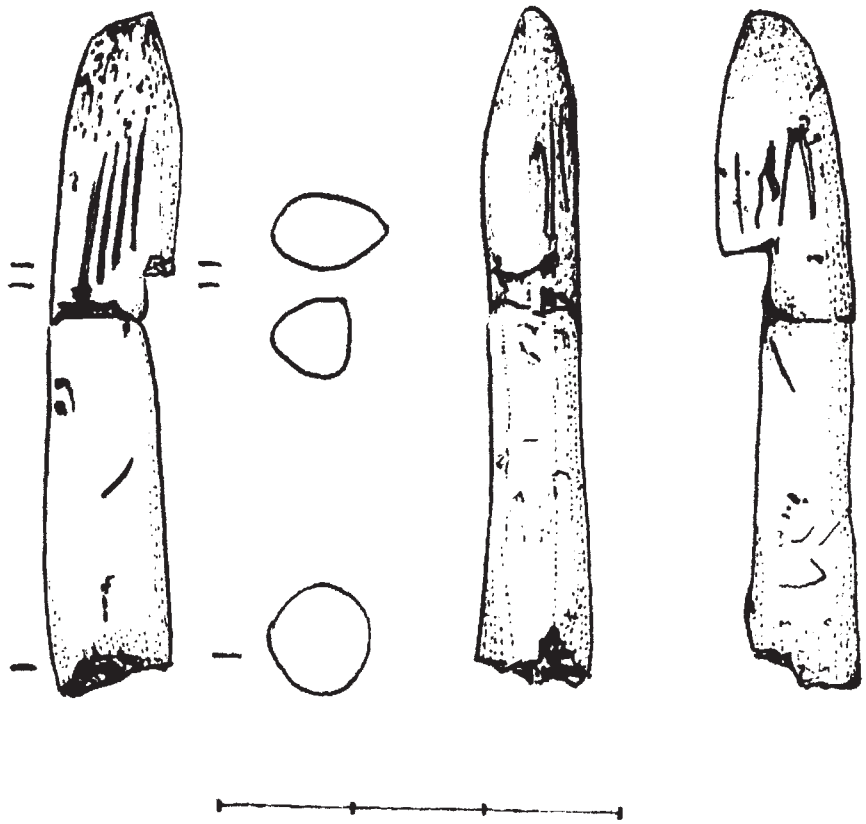

Figure 8. Reassembled fragments of worked antler recovered from Combe-Sauniere I in southwest France. These apparently represent the earliest known spear-thrower. (Redrawn from Cattelain 1989:214, Fig. 2).

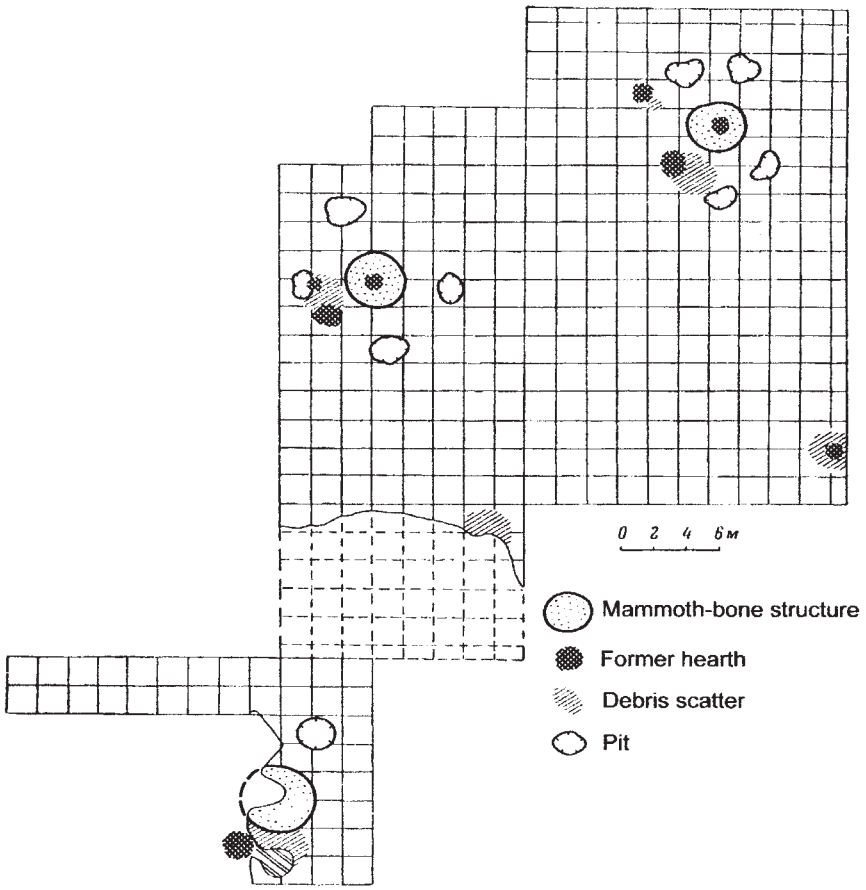

Figure 9. A group of mammoth-bone houses with associated pits, hearths, and debris scatters (activity areas) mapped at Dobranichevka (Ukraine). (Modified after Shovkoplyas 1972:178, Fig. 1).

of dwellings is less important than the broader implications of long-term settlements like Mezhirich and Plateau Parrain for the increased efficiency of food-getting technology. The variety and complexity of the latter can be inferred from the large quantities of small-mammal, bird, and freshwater-fish remains recovered from many of these sites. In maritime areas of western Europe, some sites contain the remains of marine resources, including shellfish, fish, and sometimes sea mammals.[83,97] The gradual increase in the numbers of smaller vertebrates and marine taxa suggests that the inventions and improvements in technology that facilitated their harvesting took place over an extended time.

At least some of this food-getting technology is represented directly in the archeological record. Fishing implements in the form of barbed harpoon heads are common in later Magdalenian sites and present in some younger sites of eastern Europe and southern Siberia. The earliest known fish hooks and pronged leisters appear in very late occupations such as that at Courbet (France).[107] Thousands of fox bones were recovered at Eliseevichi (Russia),[71] suggesting expanded use or improved design of traps and snares, and Mezhirich contains some possible trap components (Fig. 10).[100]

As noted, the earliest mechanical hunting technology is documented in the late Solutrean, but spear-throwers became more common in Magdalenian sites, while remaining unknown in east European and Siberian sites.[108] LUP spear-throwers may reflect an increasing command of design mechanics in terms of length and weighting.[109] Ptarmigan, grouse, and other birds may have been hunted with small darts propelled with the use of throwing boards, and some dart points are reported from Mezhirich.[100]

The production of bows and arrows is firmly documented only by 14 ka, by, for example, wooden arrow shafts and foreshafts from Stellmoor (Germany),[110] but is often inferred from the profusion of backed microliths—possible arrow tips—in earlier Magdalenian and Epi-Gravettian sites.[35] As in the case of artificial shelters of the earliest Upper Paleolithic, it is unclear if the lack of firmly documented examples simply reflects reduced visibility in the older archeological record. (Microblades are also common in Siberian sites after 21 ka, but they were almost certainly inserted into large bone and antler spear points.[44]) The design and production of bows is especially complicated, and this technology was still undergoing progressive improvement during the Neolithic and Bronze Age.[111]

Information technology seems to have been improved by LUP times, especially in western Europe. Bone fragments engraved with marks for probable use as artificial memory systems have been recovered from several Magdalenian sites, including Laugerie Basse (France) and Tossal de la Roca (Spain).[112] These fragments exhibit more organized storage of larger bodies of information than do similar artifacts found in MUP and, particularly, EUP contexts.[77] It remains unclear, however, what sorts of information were recorded by these systems.

Perhaps the most formidable achievement of the LUP lies in the realm of biotechnology. Although the identification of the remains of domesticated dogs in Epi-Gravettian sites has been considered problematic, such remains now have been documented at Eliseevichi[28] and in the somewhat younger occupation at Bonn-Oberkassel (Germany).[113] Variation in mtDNA sequences among modern dogs also suggests an LUP origin, possibly in East Asia.[114] The presence of dogs further reinforces the perceived pattern of semi-sedentary settlements, which would seem to be a prerequisite for the domestication process. The combination of bow-and-arrow technology and hunt-

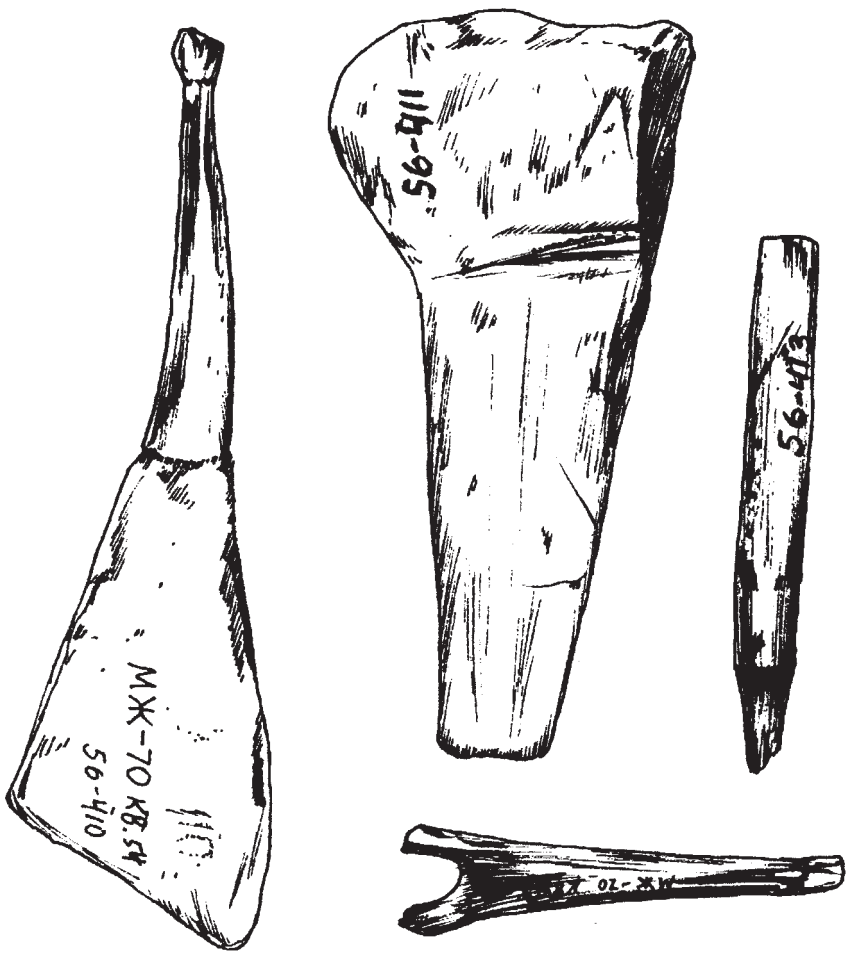

Figure 10. Possible trap components recovered from a mammoth-bone house at Mezhirich (Ukraine). (Drawn from a photograph in Pidoplichko 1976:164, Fig. 61).

ing dogs may have been especially effective.[97]

Cave art reached its highest level in terms of both quantity and diversity during the LUP of western Europe, and there is technology associated with it. At Lascaux (France), there is evidence of scaffolding comprising a wooden platform supported by horizontal poles inserted with clay adhesive into holes in the cave wall and bound with twine. Carved-handle stone lamps, probably with lichen wicks, provided artificial light.[89] The analysis of paint compounds reveals a sophisticated chemical technology that may represent a significant improvement over the EUP. Paints of various colors were mixed with plant materials and mineral pigments, and applied with a hard water $CaCO_3$-rich binding agent.[115,116]

The large and apparently long-term settlements of the European LUP suggest, as compared to the EUP, a significant increase in population density. Several variables might have influenced population growth during the Upper Paleolithic. The absence of the Neanderthals after 30 ka would have reduced competition for resources in regions they had continued to inhabit during EUP times. Biotic productivity in northern Eurasia must have varied between the later Middle Pleniglacial and Late Glacial, although it is not clear that there was a major increase in available resources during the latter period. The increased variety and efficiency of LUP technology, by expanding the range of available resources and improving per-capita energy intake, probably had raised human carrying capacity relative to the EUP. By the final millennia of the Pleistocene, modern human technology reflected a cumulative growth of knowledge inherited from the EUP and MUP (for example, notation, lamps, and storage pits). This growth of knowledge also included radical innovations such as bows-and-arrows and domesticated dogs, as well as improvements such as spear-throwers, fishing harpoons, and paint compounds.

SUMMARY AND DISCUSSION

The Upper Paleolithic record of *Homo sapiens* in northern Eurasia exhibits a pattern of technological change that is fundamentally different from those of earlier periods. Both the rapid pace of innovation and the complexity of artifact design are unprecedented, and traces of mechanical technology appear in the archeological record for the first time. A similar pattern is evident in other parts of the world and both have deeper roots in the African MSA.

Modern human technological ability seems to be an integral part of a wider package of behavior ("behavioral modernity") that developed in the context of the African MSA before 50 ka.[3,35] Modern human technology exhibits many of the characteristics, most notably the creativity and structural complexity, of art, music, ornament, and other forms of symbolism (including, by implication, syntactical language) that are elements of behavioral modernity. Modern humans, as they dispersed out of Africa after 100 ka, adapted quickly to a wide range of habitats in Eurasia with the help of novel technologies designed during the late African MSA or created in response to local conditions.[36–38]

The EUP of northern Eurasia, which spans the interval ca. 45 to 30 ka, represents the most unusual and interesting of the three major periods. It is also the least known of the three periods with respect to technological innovation, probably owing to greater time depth and smaller sample size. The most striking feature of the EUP is the technical sophistication of the sculptures, cave paintings, and musical instruments, which leads many to suspect a substantial prior history of development.[47,78] Technology related to symbolism appears comparable to that of recent foraging peoples, and

much of it probably was created in the African MSA.

By contrast, at least some EUP technology related to clothing, shelter, and food-getting activities may be uniquely primitive in comparison to that of recent foraging peoples and later periods of the Upper Paleolithic. Traces of artificial shelters and sewing needles have not been found in the oldest north Eurasian EUP sites, which may reflect belated development of these technologies some millennia after modern humans first colonized higher latitudes. Alternatively, their absence could be a function of low archeological visibility. Evidence of the harvesting of small mammals, presumably through the use of novel devices such as snares, is documented in the earliest EUP occupations.[38] But evidence of exploitation of freshwater aquatic foods, which would have required another set of innovations, is so far confined to the end of the EUP.[72,73]

Some view the EUP as a "transitional" phase between the Middle Paleolithic and the later Upper Paleolithic.[83,117] Implicit in this view is a significant degree of local continuity and at least some noncompetitive interaction between Neanderthals and modern humans. Recent research on early EUP cave paintings, sculptures, and music has underscored their complexity[78,79] and the discontinuity in symbolism with the Middle Paleolithic of northern Eurasia.[35] It is in the realm of technology and economics that the EUP seems to occupy an intermediate position between the Middle Paleolithic and the later Upper Paleolithic.

The pattern is plausibly ascribed to the less developed technology and comparatively limited technological knowledge of EUP people. As inventions and improvements accumulate during the later EUP and early MUP, corresponding increases in occupation area, site features, quantity and variety of food debris, and other measures of economic success provide a sharp contrast with the Middle Paleolithic. Like the art and music, the documented capacity for technological innovation in the EUP represents a significant discontinuity with the Middle Paleolithic.

If the EUP represents a uniquely primitive stage of technological development relative to the later Upper Paleolithic—and to recent foraging peoples who used technologies not found in the EUP—it raises the interesting possibility that EUP people also created a world-view that was unique. EUP people would have interpreted their world, or "constructed" it symbolically, on the basis of a particularly limited technological knowledge of that world in comparison to later Upper Paleolithic and post-Paleolithic peoples. Such a world-view, presumably reflected in art and traces of ritual recovered from the archeological record, might have slowed the pace of innovation during the EUP relative to later periods.

The middle Upper Paleolithic or MUP (ca. 30 to 20 ka) is characterized by a major wave of innovation that entailed both radical inventions and improvements on EUP technology. Striking changes in organization, art, and ritual are evident as well. Although some technological innovations probably were responses to colder climates and their effects on biota in northern Eurasia, other major innovations such as fired ceramics seem to have little or no relation to climate change. A significant expansion in occupation area and the diversity and quantity of food debris is apparent in many MUP sites in comparison to the preceding era. As noted, the expanding economy and population may be largely due to the improved technology of the MUP, which facilitated efficient harvesting of a variety of terrestrial and freshwater aquatic vertebrates. A contributing factor could have been an increased level of consumable foods in regions where climates of the Last Glacial Maximum favored loess-steppe flora and high mammalian biomass.

One of the more intriguing hypothetical questions of prehistory is: What if the Upper Paleolithic had begun at the end of the Pleistocene rather than 40,000 to 30,000 years earlier? Would EUP peoples such as the Ahmarians and Aurignacians have developed sedentary villages and agriculture under the same conditions that confronted the Natufians at 15 ka?[118] Or did the many millennia of Upper Paleolithic innovation and accumulated technological knowledge create the essential foundation for village agriculture and, within a few thousand years, urban civilization? Would we still be living in the late Upper Paleolithic today?

During the LUP (20 to 12 ka), more radical innovations and improvements in technology took place in northern Eurasia. The former included the first confirmed examples of mechanical technology and domestication of other living organisms (canids). The major innovations of the LUP, unlike those of the preceding periods, seem to have been spaced out over an extended period. LUP sites in northern Eurasia appear to reflect long-term occupations by relatively large groups, and the pattern is likely tied to the expanded complexity and improved efficiency of technology related to the getting, storing, and preparing of food.

In the Near East, where sedentism and agriculture developed quickly during the postglacial epoch, Upper Paleolithic innovations almost certainly laid the technological foundations of village settlement. At the remarkable site of Ohalo II (Israel), long-term occupations dating from 23.5 to 22.5 ka are linked to novel technologies for preparing plant foods (for example, possible baking ovens).[29] By LUP times, people in parts of northern Eurasia and also at lower latitudes had acquired considerable knowledge about their environment through a rapidly expanding and increasingly complex body of technology. The accumulation of technological knowledge must have had a significant influence on how LUP people interpreted their world. This, in turn, probably affected further developments in technology. The evolving LUP worldview may have been as critical to the origins of sedentism and agriculture as its technological legacy.

ACKNOWLEDGMENTS

I thank John G. Fleagle for inviting me to contribute this paper to Evolutionary Anthropology, and several anonymous reviewers for their comments on two drafts. I am also grateful to Steve Holen, Art Joyce, Michael Lightner, Steve Lekson, Bob Levin,

and Paola Villa for their comments and suggestions. Research at Kostenki has contributed significantly to the study of Upper Paleolithic technological innovation, and I am grateful to my colleagues M. V. Anikovich, A. A. Sinitsyn, V. V. Popov, V. T. Holliday, G. M. Levkovskaya, and others with whom I worked at these sites from 2001 to 2004, with support from the National Science Foundation (BCS-0132553) and the Leakey Foundation. Figures 2, 7, 8, and 10 were prepared by Ian Torao Hoffecker.

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