Complex Projectile Technology and *Homo sapiens* Dispersal into Western Eurasia

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ABSTRACT

This paper proposes that complex projectile weaponry was a key strategic innovation driving Late Pleistocene human dispersal into western Eurasia after 50 Ka. It argues that complex projectile weapons of the kind used by ethnographic hunter-gatherers, such as the bow and arrow, and spearthrower and dart, enabled *Homo sapiens* to overcome obstacles that constrained previous human dispersal from Africa to temperate western Eurasia. In the East Mediterranean Levant, the only permanent land bridge between Africa and Eurasia, stone and bone projectile armatures like those used in the complex weapon systems of recent humans appear abruptly ca 45–35 Ka in early Upper Paleolithic contexts associated with *Homo sapiens* fossils. Such artifacts are absent from Middle Paleolithic contexts associated with *Homo sapiens* and Neandertals. Hypotheses concerning the indigenous vs. exogenous origins of complex projectile weaponry in the Levant are reviewed. Current evidence favors the hypothesis that complex projectile technology developed as an aid to ecological niche broadening strategies among African populations between 50–100 Ka. It most likely spread to western Eurasia along with dispersing *Homo sapiens* populations. Neandertals did not routinely deploy projectile weapons as subsistence aids. This puzzling gap in their otherwise impressive record for survival in some of the harshest environments ever occupied by primates may reflect energetic constraints and time-budgeting factors associated with complex technology.

INTRODUCTION

In evolution, only differences matter—differences in genes, differences in morphology, differences in behavior, differences in reproductive success, and differences in geographic dispersal. With respect to dispersal, there appear to have been two strikingly-different phases in *Homo sapiens*' Pleistocene evolutionary history. From our earliest appearance in the fossil record ca 195 Ka (Fleagle et al. 2008) to around 50 Ka, *Homo sapiens* remained largely an endemic African species. *Homo sapiens'* only demonstrable excursion from Africa prior to 50 Ka involved a short-lived dispersal into the East Mediterranean Levant between 75–130 Ka (Shea and Bar-Yosef 2005). After 50 Ka there is clear and unambiguous evidence for *Homo sapiens* dispersal from Africa to the rest of the Old World (Grine et al. 2007; Tishkoff and Verrelli 2003; Trinkaus, 2005; see papers in Mellars et al. 2007). Evidence for this dispersal is stronger in western Eurasia than in southern or eastern Asia and Sahul (Pleistocene New Guinea and Australia). Yet, nothing that archaeologists have found in these regions refutes the hypothesis that *Homo sapiens* underwent a vast geographic dispersal ca. 50 Ka (Dennell 2009; O'Connell and Allen 2007).

The rich array of euphemisms bestowed on the 50 Ka dispersal event include "The Human Revolution" (Mellars and Stringer 1989), "The Upper Paleolithic Revolution" (Bar-Yosef 2002; Mellars 1994), and even "The Great Leap Forward" (Shreeve 1995). These terms reflect a widely-shared belief that the human populations who dispersed ca 50 Ka differed behaviorally from earlier African humans. Complex behaviors previously only seen episodically in Africa and Southwest Asia became consistent features in the archaeological record wherever *Homo sapiens* fossils were deposited (Hovers and Belfer-Cohen 2006; McBrearty 2007; McBrearty and Brooks 2000; Mellars 2007; Shea 2006a, 2007a; Willoughby 2007). These behaviors include long-distance material transfers, the labor-intensive production of tools from stone and osseous tissues, elaborate exosomatic symbolic behavior (e.g., personal adornment), and complex subsistence strategies ranging from specialized big-game hunting to broad-spectrum foraging. In those parts of the Old World near Africa, first appearance dates for *Homo sapiens* outside of Africa frequently correspond closely with local and regional last appearance dates for other hominin species, such as the Neandertals (Mellars 2006a). In regions further afield, such as Sahul and the Americas, there is a suspiciously close chronological correlation between the appearance of *Homo sapiens* and large mammal extinctions (Martin 1984). *Homo sapiens*' role (if any) in the extinction of the Neandertals, of penecontemporaneous Asian hominins, and of other large mammals remains uncertain and hotly disputed (Grayson 2001; Zilhao 2006).

In searching for explanations for the success of the 50 Ka *Homo sapiens* dispersal, uniformitarian principles suggest we should start by examining modern-day evolution-

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ary processes whose outcomes are structurally analogous to those patterns in the paleoanthropological record that we are trying to explain. Since the end of the Pleistocene *Homo sapiens* has undergone rapid population growth and an extension of our geographic range as the result of technologically-assisted strategies for niche-broadening. The most recent and consequential of these strategies are agriculture and pastoralism. Yet, agriculture and pastoralism are strategic innovations of Holocene antiquity, possibly because wide Pleistocene paleoenvironmental variability militated against their development in earlier times (Richerson et al. 2001). The use of complex projectile weaponry is a universal human technological/subsistence strategy thought to have a Pleistocene antiquity of at least 50 Ka (Shea 2006b, 2009b). As such, it is a plausible factor in the 50 Ka human dispersal.

Projectile technology is niche-broadening technology. Its universal distribution among recent humans almost certainly indicates that it confers a significant ecological advantage. Complex projectile weapons, like the bow and arrow, and spearthrower and dart, enable humans to exploit a far greater range of potential animal prey than our near primate relatives do. Recent humans use complex projectile weapons against prey ranging from elephants to rodents, against terrestrial, avian, and aquatic species (Churchill 1993). Compared to heavy hand-cast spears, complex projectile weapons have a greater effective range, are more readily transportable, and allow multiple shots at a target (Yu 2006). The bow and arrow, in particular, offers the further advantage of being usable in three dimensions. One can launch arrows up, down, or horizontally with equal effect. All these factors significantly reduce post-encounter energetic costs of predation to humans equipped with complex projectile weapons. Theoretically, the long-term consequences of such reduced costs ought to have included stabilized foraging returns, population growth, and geographic dispersal.

This paper considers the role of complex projectile technology in *Homo sapiens*' Late Pleistocene dispersal. We focus on the dispersal into western Eurasia through the Levant, because this region offers a rich set of data with which to test the hypothesis that complex projectile technology was a major factor in human dispersal against other hypotheses.

EXPLAINING THE 50 KA *HOMO SAPIENS* DISPERSAL

The principal hypotheses currently invoked to explain the 50 Ka dispersal into western Eurasia focus on either: (1) cognitive changes leading to greater use of symbolism and, by implication, language (Coolidge and Wynn 2009; Deacon 1997; Deacon and Deacon 1999; Gamble 2007; 2008; Henshilwood and Marean 2003; Klein 1995; Mithen 1998; Wadley 2001); (2) population increases culminating in the formation of extensive alliance networks, (Ambrose 1998; McBrearty and Brooks 2000; Powell et al. 2009; Stiner and Kuhn 2006); and, (3) some combination of both factors (Chase 2006; Clark 2002; d'Errico 2007; Mellars 2006b; Soffer 1994). Cognitive changes and population pressure are plausible factors in dispersal, but both are difficult to investigate in ways that allow hypotheses about them to be conclusively refuted with archaeological evidence.

Measuring variation in human cognition and characterizing symbol use is problematical even among living populations (Gould 1981; Hodder 1982). In assessing prehistoric cognition, the best that most archaeological investigations can do is to assert a hominin population possesses "modern" human abilities because their archaeological record contains artifacts that resemble exosomatic symbols used by recent humans. There have been more nuanced efforts to analyze prehistoric cognition from the archaeological and paleontological evidence (Coolidge and Wynn 2009; Mithen 1996), but in actual practice, archaeologists usually rate prehistoric cognition as "modern," or not. Symbol use is often the bellwether of such modern cognition (Henshilwood and Marean 2003); yet, much human symbol use involves things that do not fossilize, such as spoken language, gesture, and perishable media. This raises the possibility that archaeologists might mistakenly infer the absence of symbol use simply from an absence of preserved evidence. A shift to rendering symbolic artifacts in durable media might appear to be the beginning of symbol use rather than a change in a long-extant habit. Thus, in a comparison of symbolic evidence from two contexts, similar evidence can legitimately be taken as evidence of similar abilities, but differences remain subject to multiple interpretations.

Questions about population size are some of the most difficult ones for archaeologists to answer with any degree of precision. If modern nation-states have to spend millions of dollars and complex statistical tools to accurately estimate their own populations through census, one has to expect that archaeologists' casual efforts to estimate prehistoric population size variation are likely to be fraught with even greater problems. Most such studies are based on recent human hunter-gatherer demography (Binford 2001; Powell et al. 2009; Wobst 1974; Zubrow 1991). Yet hunter-gatherer population sizes and densities are widely-variable, even among populations living under similar ecogeographic conditions (Kelly 1995). Some of the ambiguity in these estimates reflects the widely variable methods used to gather these demographic data. But, it is also the case that such variability is an intrinsic quality of human hunter-gatherer adaptation. Forager societies often cope with resource shortfalls and conflicts by altering their distribution and density on the landscape. Moreover, they can do this quickly, situationally, and recursively. Because hunter-gatherers adapt to landscapes, while archaeologists sample locations in incompletely-preserved landscapes, it is difficult to incorporate these qualities of landscape-level variability into estimates of Pleistocene human population size and density. For example, evidence for population increase at one or more sites may not so much reflect region-wide population increases but rather aggregations of humans around those localities, or "population packing" (Binford 2001).

These considerations do not refute hypotheses that cognitive and/or demographic changes played a role in Late Pleistocene human dispersal; but, they do suggest we should continue to search for other factors leading to that dispersal. Projectile technology has been named among the derived features of the 50 Ka dispersal, but it has usually been portrayed as of secondary importance to cognitive and social-demographic processes (Bar-Yosef 2002; Binford 1970; Dennell 1983; Gilman 1984; Henshilwood and Marean 2003; Klein 1998; Klein and Edgar 2002; Mellars 1973; White 1982). Recent improvements in archaeologists' ability to detect projectile weapon use in the Paleolithic suggest the role of projectile technology in human dispersal needs to be re-evaluated (Brooks et al. 2006; Churchill and Rhodes 2009; Lombard and Pargeter 2008; Shea 2006b; 2007a; 2008; 2009b).

Archaeologists use a variety of terms to describe projectile technology (Knecht 1997). It is important to parse these terms before discussing the prehistoric record. We use the term "complex projectile technology" to refer to weapons systems that use energy stored exosomatically to propel relatively low mass projectiles at delivery speeds that are high enough to allow their user to inflict a lethal puncture wound on a target from a "safe" distance. The most widespread such weapons systems are the bow and arrow, and the spearthrower and dart. The bow and arrow stores energy in the flexion of the bow. The spearthrower stores energy in the flexion of the dart.

Some prehistorians also include hand cast spears, stones, throwing sticks, and other missiles among "projectile weapons." We refer to these as "simple" projectile weapons because they do not involve exosomatic energy storage. They are launched at their targets with unassisted bodily force. Simple projectile weapons are relatively heavy, slow-moving, and must be used at close quarters to their intended targets. It is true that some highly-trained athletes can throw spears and rocks impressive distances, but such weapons lose kinetic energy at a rapid rate. They are notoriously difficult to aim at such distances, and they offer few tactical advantages against small mobile prey. Against larger uninjured prey with "proactive" antipredator defenses, they offer few advantages at all. A healthy adult American bison or Cape buffalo can charge 50 meters in a matter of seconds. Ethnographic throwing spears are usually delivered from around 8–10 meters on average and used to dispatch prey already incapacitated by other means (Churchill 1993). Thus, the 2.5 meter-long wooden spears recovered from Middle Pleistocene contexts at Lehringen and Schöningen (Germany) can be viewed as simple projectile weapons, but not complex projectile weapons (Schmitt et al. 2003). Clubs, thrusting spears, and other weapons held in the hand during delivery are, by definition, not projectile weapons, nevertheless, some prehistoric projectile weapons may have been used in both projectile and non-projectile tasks, much as ethnographic projectile weapons are used today (Greaves 1997).

EVIDENCE FROM THE LEVANT

The "Levant" is a that part of Southwest Asia and the eastern Mediterranean encompassed by the modern states of Lebanon, Syria, Israel, Jordan, the Palestinian National Authority, and adjacent parts of Turkey, Iraq, Egypt, and Saudi Arabia. Ecologically, the Levant is defined by the Mediterranean oak-terebinth woodland and its ecotone with the Irano-Turanian steppe (Blondel and Aronson 1999). The Levant is a kind of transition zone between Africa and Eurasia. The flora and fauna of the Middle-Late Pleistocene Levant were overwhelmingly Eurasian (i.e., Palearctic) (Tchernov 1988); nevertheless fauna now endemic to Africa, including hippopotamus, rhinoceros, warthog, zebra, ostrich, and other Afro-Arabian fauna once ranged freely in this region (Kingdon 1990). For much of the Pleistocene, the Levantine "corridor" has been the only permanent land bridge linking Africa and Eurasia. It also straddles the boundary between the Mediterranean Basin and the Indian Ocean. As such, it is a convenient place in which to monitor the movement of hominin species and diffusion of ideas around the Old World.

LEVANTINE LATE PLEISTOCENE PREHISTORY

The archaeological record for the Late Pleistocene Levant is divisible into three major phases, "Interglacial Middle Paleolithic" (IMP), the Later Middle Paleolithic (LMP), and the "Early Upper Paleolithic" (EUP).

The IMP lasted between 80–130 Ka and is roughly coterminous with Marine Oxygen Isotope Stage 5, or the Last Interglacial, *sensu lato*. Dated IMP archaeological contexts include Tabun Cave Unit I (Garrod's Levels B–C), Skhul Cave Level B, Qafzeh Caves Units XVII–XXIV, Douara Cave Unit IIIB, Hayonim Cave Layer E (Unit 2), Nahr Ibrahim, and the Enféan II and Naaméan beaches at Naamé (Figure 1). Shea (2003a) provides a recent overview of the evidence from these and other IMP sites (see also Bar-Yosef 2000). Levantine prehistorians group IMP stone tool assemblages together into the "Tabun C-Type" Levantine Mousterian, which is named after major geological units in Garrod's stratigraphy of Tabun Cave on Mount Carmel. Core reduction strategies in these assemblages emphasize radial-centripetal preparation and the production of large oval Levallois flakes. Prismatic blades are relatively rare, and carved bone/antler tools are unknown. Hominin fossils from IMP contexts consist primarily of the *Homo sapiens* fossils from Skhul and Qafzeh (Rak 1998). Neandertal fossils also are known from the upper part of Tabun Cave Unit I (Levels B and C), but the stratigraphic provenance of these fossils are problematical (Bar-Yosef and Callendar 1999).

The LMP spans the period from 75–45 Ka, encompassing MIS 4 and the early part of MIS 3. Archaeological contexts dating to this period and containing hominin remains include Amud Cave Levels B1–4, Dederiyeh Levels 3–11, Geula Cave B Level B1/B2, Kebara Cave Units VI–XII, Shovakh Cave "Lower Cave Earth," and Shukhbah Cave Level D (Figure 2). LMP archaeological assemblages not associated with hominin fossils include Boker Tachtit Level 1, Biqat

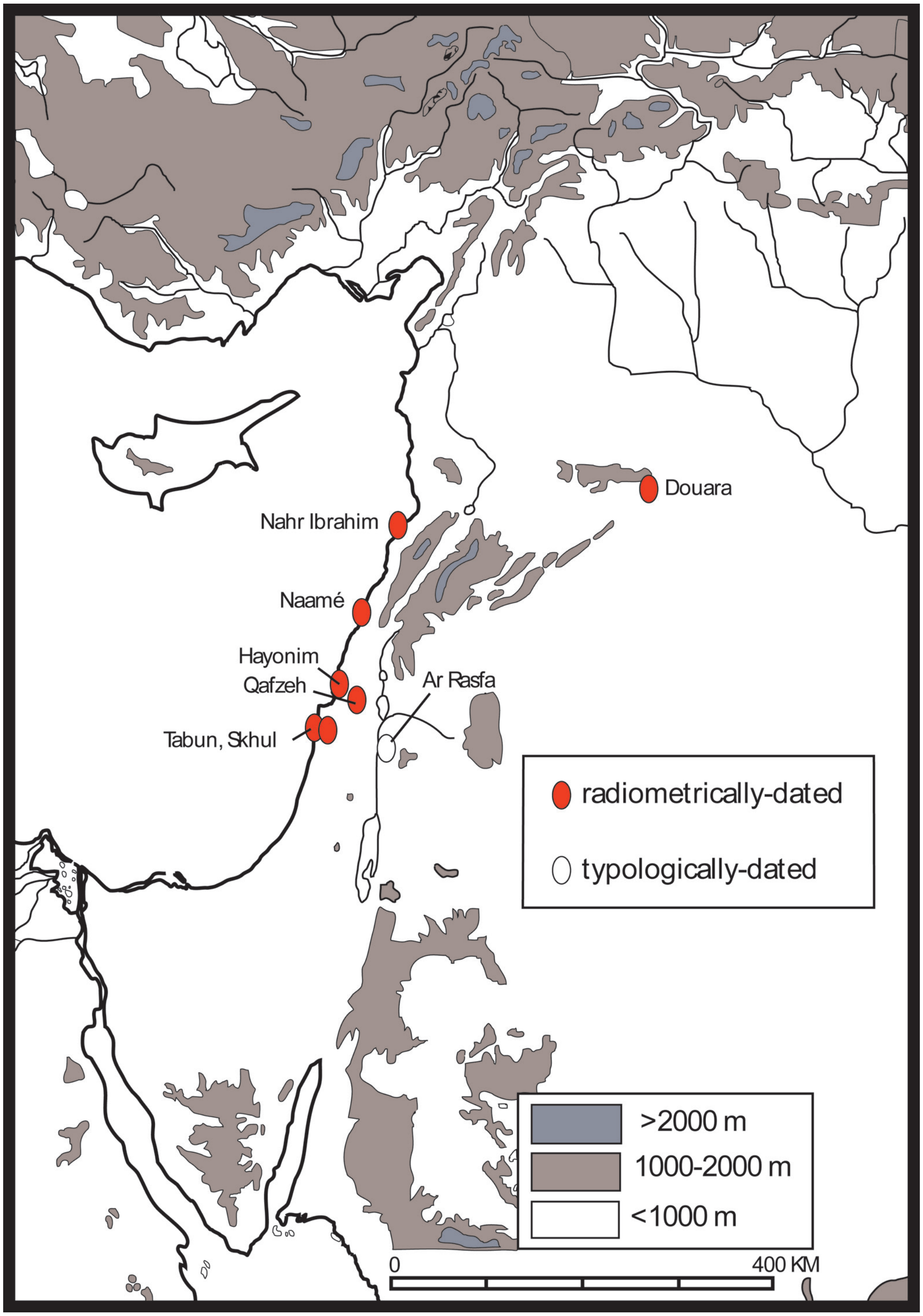

Figure 1. Map showing IMP sites mentioned in the text.

Quneitra, Far'ah II, Jerf Ajla Cave Level C, Ksar Akil Rockshelter Level XXVI, Tor Faraj Level C, and Tor Sabiha Level C. LMP lithic assemblages show frequent use of recurrent unidirectional-convergent core preparation, as well as variable amounts of radial-centripetal preparation. There is evidence for prismatic blade production, but it is rare and follows a different set of procedures than those methods predominating among EUP assemblages. All LMP hominin fossils thus far discovered are either Neandertals, or they are too fragmentary for the morphological affinities to be conclusively assessed.

The Upper Paleolithic period began around 47 Ka and lasted to around 19 Ka. This paper focuses on the evidence from 47–28 Ka, or the EUP, that part of the Upper Paleolithic that is prior to the Last Glacial Maximum. The EUP has a relatively rich archaeological record, one recently reviewed in detail by Belfer-Cohen and Goring-Morris (2003; see also Shea 2007a). Well-documented EUP contexts include Boker

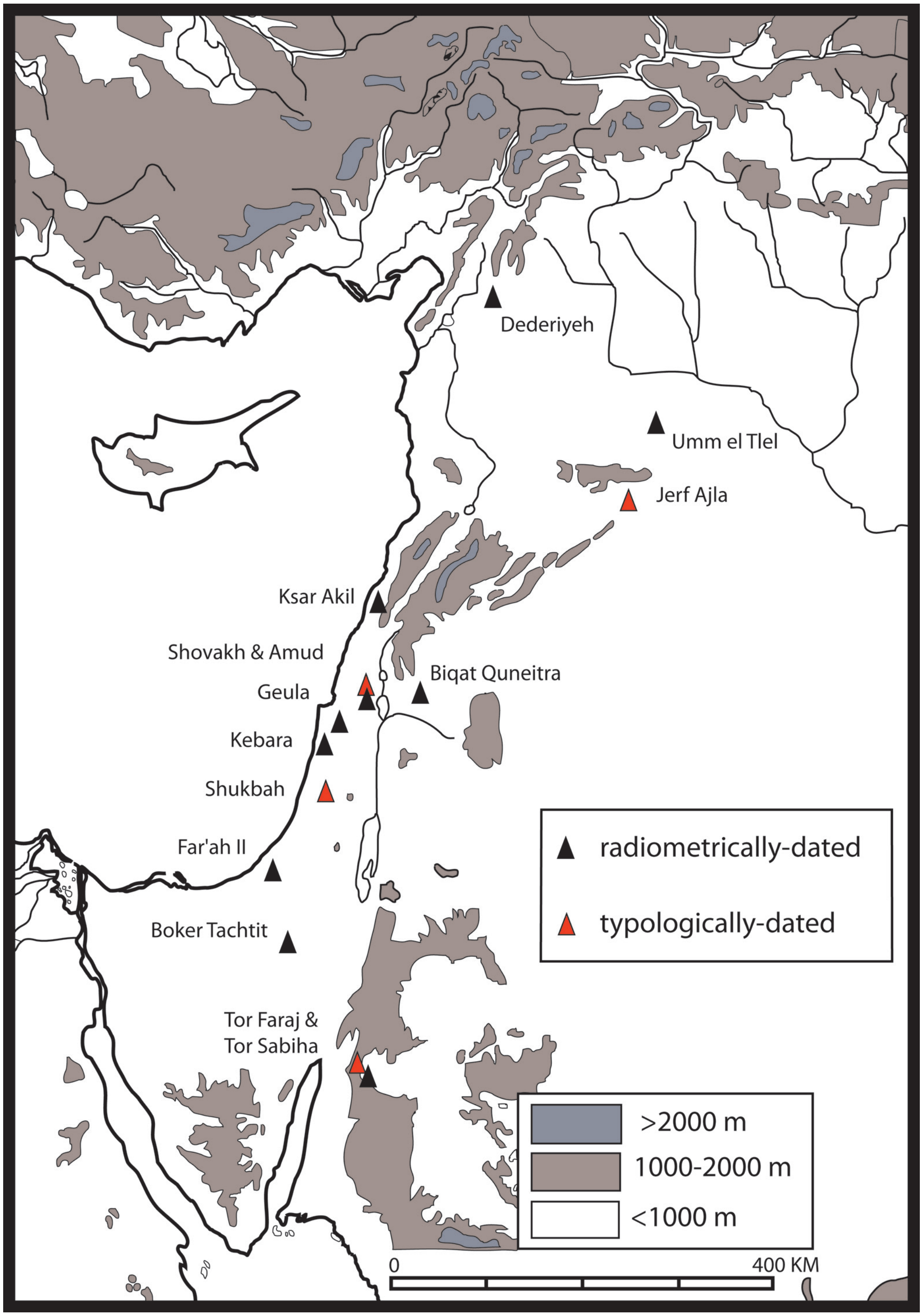

Figure 2. Map showing LMP sites mentioned in the text.

A Level 1, Boker BE Levels I–III, Boker Tachtit Level 4, Hayonim Layer D, Kebara Cave Units I–IV/Levels D–E, Ksar Akil Levels IV–XXV (phase III–VII), Lagama IIID, VII, and VIII, Qafzeh Cave Levels C–E/ 4–11, Üçagizli Cave Layers B–H, Umm el Tlel 2 Levels V–XI, Umm el Tlel III2a (late MP), and Wadi Abu Noshra I, II, and VI (Figure 3). Several dozen additional assemblages can be assigned to the EUP on the basis of stone tool typology. Most lithic assemblages from the EUP feature prismatic blade and bladelet cores, and laminar debitage is common. Levantine prehistorians subdivide EUP assemblages into named industries, including the Initial Upper Paleolithic/Emiran, the Ahmarian, the Levantine Aurignacian, and a fourth unnamed flake-based industry, on the basis of variation in retouched tool types and the relative frequencies of blades and bladelets. A variety of carved bone/antler implements have been recovered from EUP contexts. EUP human fossils include the burials from Ksar Akil, two sets of cranial remains from Qafzeh,

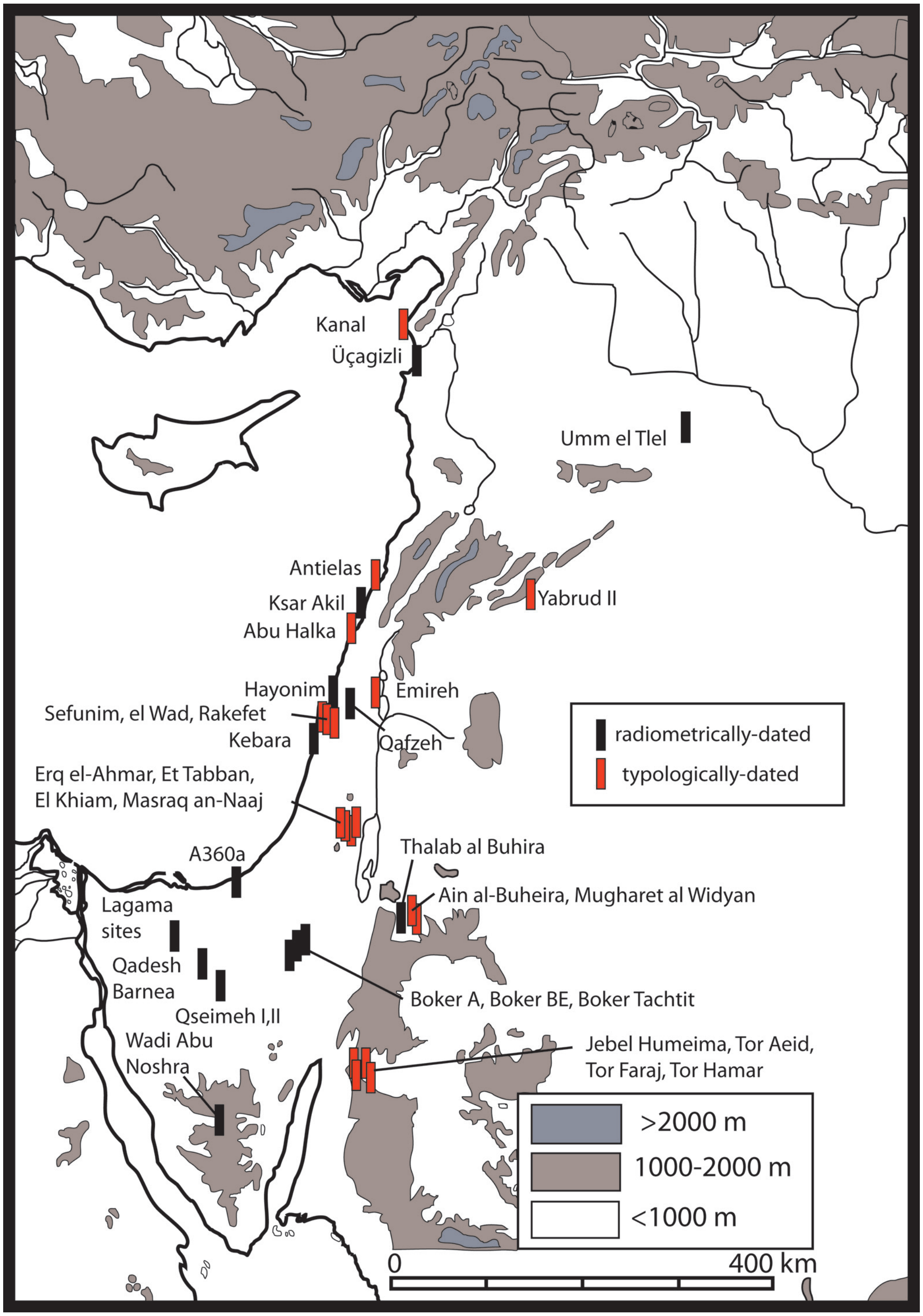

Figure 3. Map showing EUP sites mentioned in the text.

and fragmentary remains from Hayonim Level D. The Ksar Akil and Qafzeh fossils are remains of *Homo sapiens* (Smith 1995). Ten isolated teeth recently recovered from EUP levels of Üçagızli Cave also are identified as *Homo sapiens* (Gulec et al. 2007).

SIMILARITIES AND DIFFERENCES

The many similarities among the evidence for IMP, LMP, and EUP behavior match what one would expect to see among humans possessing similar needs for shelter, food, and tools, and living in broadly comparable environments. They do not necessarily indicate a shared social identity or a close evolutionary relationship. Indeed, only Neandertal fossils are known from Levantine contexts dating to between IMP and EUP periods (45–75 Ka), raising the possibility of an interruption in *Homo sapiens* occupation of the Levant (Shea 2008).

Table 1 summarizes the main differences between the

TABLE 1. BEHAVIORAL DIFFERENCES INFERRED FROM IMP VS. EUP ARCHAEOLOGICAL EVIDENCE.

Behavioral Variable	IMP (130–75 Ka)	LMP (75–45 Ka)	EUP (45–25 Ka)
Settlement in steppe-desert	No	Yes	Yes
Systematic hunting/gathering of small mammals, birds, reptiles	No	No	Yes
Predominant core reduction strategy	Discoidal and Levallois core reduction	Laminar and discoidal Levallois core reduction	Prismatic blade/bladelet core reduction
Stone tools distinctive from those made at different times in adjacent regions	No	No	Yes
Patterned stylistic variation among stone tools in Levant	No	No	Yes
Carved bone/antler artifacts	No	No	Yes
Burials with mortuary furniture	Yes	Possibly Amud 4	No
Mineral pigment production	Yes	No	Yes
Personal adornments	Shells, possibly modified	No	Shells and teeth, clearly modified
Dispersal beyond the Levant	No	No	Yes
Stone and bone projectile armatures	No	No	Yes

Levantine IMP, LMP, and EUP records (see also Shea 2007a, 2008, 2009a). EUP and LMP humans appear to have settled in arid, low-productivity habitats to a greater extent than their IMP counterparts (Henry 1998). Levantine EUP subsistence differs from the LMP and IMP in more systematic exploitation of smaller animals and sessile prey (rodents, lagomorphs, birds, tortoises)(Rabinovich 2003; Stiner 2006). EUP lithic assemblages differ from IMP and LMP ones in the use of microlithic technology and in the production of tools from osseous materials (Shea 2006a). Burials of adults and children are known from all periods, but clear examples of exosomatic symbolic artifacts, such as red ochre and perforated shells are known only from the IMP and EUP (Hovers et al. 2003; Kuhn et al. 2001; Shea and Bar-Yosef 2005). Whereas stone tools from IMP and LMP contexts are similar to contemporaneous tools made throughout much of Europe and Africa, stone tools from EUP contexts differ from those made at the same time in adjacent regions. EUP lithic assemblages also preserve evidence for internal stylistic variation that is not paralleled by variation among IMP and LMP contexts (Belfer-Cohen and Goring-Morris 2003; Shea 2007a).

Dispersals of varying degrees of success mark the Levantine Late Pleistocene paleoanthropological record. *Homo sapiens* was present in the Levant 80–130 Ka, but the archaeological record for this period does not preserve evidence for dispersals further northwards into temperate western Eurasia. The presence of Neandertals in LMP contexts is seen by some researchers as reflecting movements of Neandertals into the Levant from montane western Asia, either as the result of climatic forcing during the rapid onset of glacial conditions ca. 75 Ka (Bar-Yosef 1988; Serangeli and Bolus 2008), or as the result of their own adaptive innovations. Neandertals did not demonstrably disperse further south into the Arabian Peninsula or into Africa. Only EUP humans dispersed successfully through the Levant to elsewhere. Improved radiocarbon chronology for the earliest Upper Paleolithic contexts in Europe increasingly point to a dispersal of Ahmarian-affiliated "Fumanian" assemblages from the Levant to southern Europe beginning shortly after 45 Ka (Mellars 2006a). Artifactual similarities between Levantine EUP assemblages and North Africa "Dabban" ones further hint at a possible EUP dispersal from the Levant to North Africa during EUP times (Iovita 2009).

SYMBOL USE AND POPULATION DENSITY

That Levantine IMP humans possessed a symbolic capacity similar to that of post-50 Ka humans seems clear from the numerous burials, perforated shells, and fragments of mineral pigment recovered from Skhul, Qafzeh, and other sites (Bar-Yosef Mayer et al. 2009; Kuhn et al. 2001; Vanhaeren et al. 2006). Nevertheless, there are a few differences. IMP burials incorporated nonhuman skeletal remains as mortuary furniture, while EUP burials apparently did not (admittedly the sample is small). EUP humans manufactured perforated ornaments from human and animal teeth, a practice that is not known from IMP contexts. Such differences are comparable in scale to variation in symbolic behavior among ethnographic human societies. They are not compelling evidence for differences in cognitive and symbolic capacities.

The duration of the EUP was half that of the IMP; yet, dated EUP contexts outnumber IMP ones by more than two to one, and they are far more broadly distributed in the Levant (compare Figures 1 and 2). This would seem to argue for larger EUP populations, but this is not necessarily true. Much less of the IMP and LMP landscape is preserved simply as a function of erosion. Moreover, the recognition criteria for IMP, LMP, and EUP assemblages differ widely. EUP assemblages contain diagnostic artifact-types, such as Ksar Akil, El Wad and Emireh points, *chanfrein* scrapers, and various other tools that enable even small surface oc-

TABLE 2. SUMMARY STATISTICS OF DELTA-^{18}O VALUES FOR SPELEOTHEMS FROM PEQIIN AND SOREQ CAVES, ISRAEL (Source Data: Bar-Matthews et al. [2003b]).

Samples	Statistic	Peqiin Cave	Soreq Cave
EUP (25-45 Ka)	mean	-4.1463333	-3.7676169
	sd	0.49436468	0.41405035
	n	29	449
LMP (45-75 Ka)	mean	-4.3126136	-3.7656757
	sd	0.40979528	0.40657157
	n	88	444
IMP (75-130 Ka)	mean	-6.0253646	-5.1543494
	sd	1.01942334	0.89775611
	n	192	269

currences to be identified as such. IMP and LMP assemblages differ little from Middle Paleolithic assemblages that precede them, mostly in terms of relative frequency variation of artifact-types and different core-reduction methods. Absent large samples of artifacts from excavated, radiometrically-dated contexts, it is difficult to assign a lithic assemblage specifically to the IMP or LMP. In fact, many Levantine prehistorians lump the two periods together into a single undifferentiated "Later Levantine Mousterian,"

So few IMP, LMP, and EUP sites are known that it is difficult to frame a precise estimate of population size or density. Stiner and colleagues (1999) argue that higher levels of small animal exploitation in EUP assemblages indicate higher population densities in the Upper Paleolithic. Yet, the EUP zooarchaeological samples in question date to less than 36 Ka, long after the initial phase of human dispersal. Though higher population densities may have influenced social behavior and evolutionary processes towards the end of the EUP, there is at present no strong evidence to support the hypothesis of high initial EUP population densities one would expect to see if population growth was a driving force in the 50 Ka dispersal.

More specific quantitative estimates for Pleistocene human populations can be derived from demographic data on hunter-gatherer societies living in temperate habitats with similar effective temperature indices to the Levant and by integrating these data with paleoclimatic evidence from isotopic analysis of speleothems (Shea 2007b). Mediterranean woodland species dominate IMP, LMP, and EUP faunal assemblages, and archaeological sites hew closely to the known core areas of Mediterranean woodland vegetation. The productivity of these woodlands is strongly correlated with rainfall and temperature (Blondel and Aronson 1999). Oxygen-isotope values of speleothems from Israeli caves for the IMP, LMP, and EUP contrast with one another (Table 2). Mean delta ^{18}O values for the IMP approximate those of the present day, while those for the EUP and LMP are nearly 30% lower (Figure 4). These data indicate that, even though rainfall and temperature varied widely during both periods, the IMP was significantly warmer, more humid, and significantly more variable than either the LMP or EUP (Bar-Matthews et al. 2003a). During EUP times, the Levantine climate was consistently cold and dry. Pollen evidence indicates that Mediterranean woodlands were restricted to coastal refugia (Cheddadi and Rossignol-Strick 1995). A model of Levantine human population densities based on recent human hunter-gatherers (and thus probably an over-estimate), projects a EUP population as few as 200–1,600 people (assuming a Mediterranean woodland at 25% of its current extent)(Shea 2007b). Under humid conditions like those prevailing today, IMP human populations may have been significantly larger, perhaps 800–6,400 people (assuming a Mediterranean woodland of comparable extent to the present day). Even if the details of this estimate are wrong, the underlying principles suggest that selective pressure for human dispersal arising from population growth would likely have been greater among IMP humans than among LMP and EUP ones.

There is a long-running debate about the functions of Levallois and Mousterian points from Levantine Middle Paleolithic contexts, but none of the major parties to this debate interpret such artifacts as complex projectile weapon armatures, i.e., as either arrowheads or dart tips (Holdaway 1989; Plisson and Béyries 1998; Shea 1988; Solecki 1992), and experimental tests suggest they are not effective armatures for complex projectile weapons (Sisk and Shea 2009). EUP assemblages feature many narrow, pointed flaked stone and carved bone points that Levantine prehistorians routinely interpret as armatures for complex projectile weapons.

EVIDENCE FOR PROJECTILE TECHNOLOGY

Detecting the use of projectile weaponry in the prehistoric record is not a simple or straightforward proposition. Most recent projectile weapons are made largely of wood, string, glue, and other perishable media that are only preserved under the rarest of circumstances. Paleolithic art and skeletal lesions can sometimes indicate the use of bows or spearthrowers, but most such art and skeletal lesions are recent, rare, and subject to differing interpretations, even

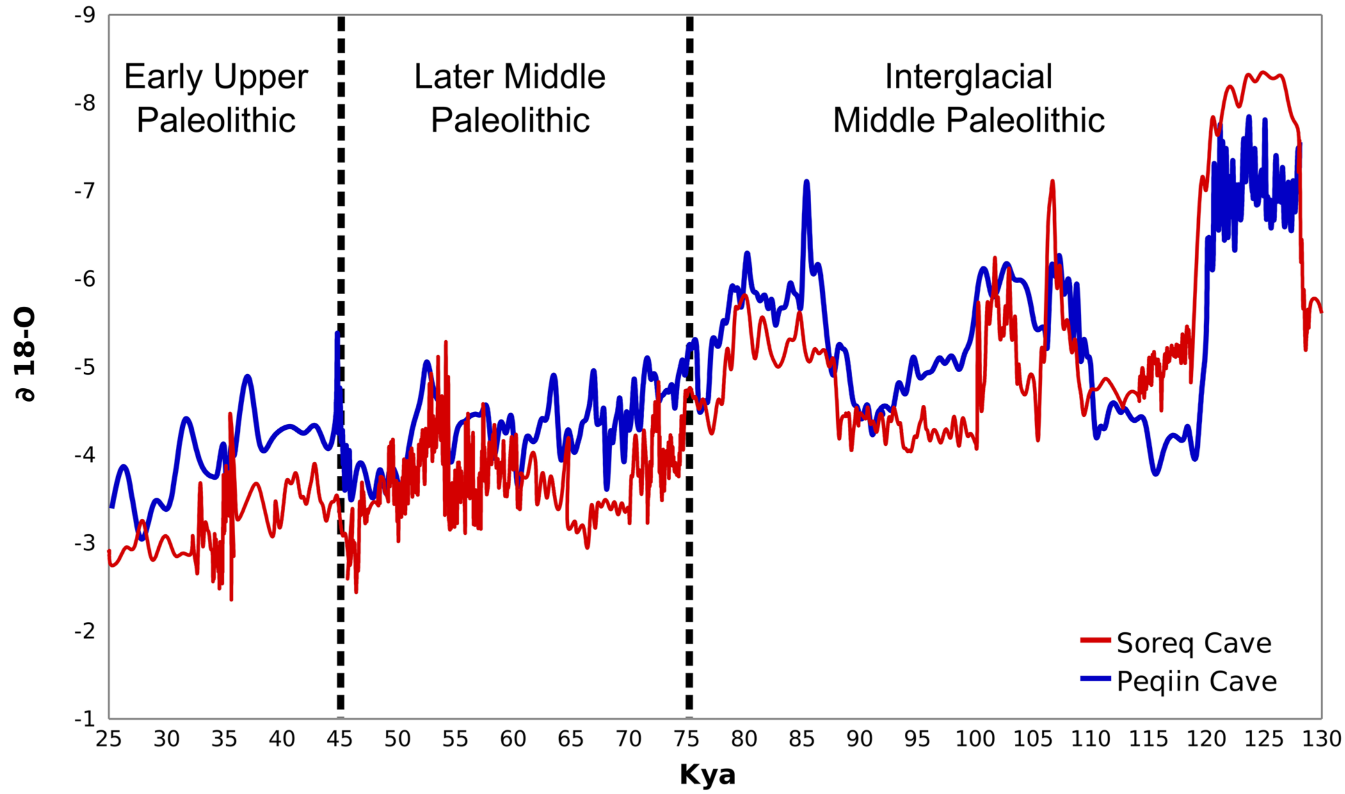

Figure 4. Chart of δ¹⁸O values for speleothems from Soreq and Peqiin Caves in Israel. Increases in δ¹⁸O values correspond to decreases in rainfall and temperature in the coastal Levant. Note the increases associated with the beginning of the MMP, as well as the "transitions" between MMP-LMP and LMP-EUP. The broken horizontal line indicates approximate contemporary δ¹⁸O value. Source Data: Bar-Matthews et al. (2003b).

by experts (Churchill et al. 2009; Guthrie 2005).

METHODS

Archaeological efforts to detect projectile weapons focus on durable weapon components, such as stone or bone/antler points and barbs. Experiments suggest that (at least for arrows) projectiles made of wood do not withstand repeated use as well as do projectiles tipped with bone or stone armatures (Waweru 2007). The benefits of mounting such armatures are likely correlated with prolonged and repeated use. This suggests that there are "thresholds" of projectile weapon use below which the benefits of durable weapon armatures do not accrue and projectile weaponry may be archaeologically "invisible." Furthermore, carving bone/antler points requires vastly more time than knapping stone points (a cost presumably recouped by weapon durability). This suggests that stone weapon armatures are more sensitive registers of frequent projectile weapon usage than points made of osseous tissues.

A variety of measurements have been proposed for use in differentiating prehistoric stone projectile points (Hughes 1998). Of these, tip cross-sectional area (TCSA) has proven useful and widely applicable to points from many different archaeological contexts (Shea 2006b). Because most points are either lenticular or triangular in cross-section, a reasonable approximation of their actual TCSA can be calculated by the following formula:

0.5 x Maximum Width in mm x Maximum Thickness in mm

Measurements of ethnographic and archaeological projectile points still attached to their shafts offer a comparative database of points of known function (Table 3). These include 118 arrowheads and 10 spearthrower dart tips from the collections of the American Museum of Natural History measured by Thomas (1978) and 30 dart tips from other museums measured by Shott (1997). The 118 hafted arrowheads have a mean TCSA value of 33mm² (sd=20). TCSA values of Thomas's and Shott's dart tip samples do not differ from each other significantly (t=0.38, p =>.01). The mean TCSA of this pooled dart tip sample is 58mm² (sd=18). The TCSA values of the arrowheads and pooled dart tip samples differ from each other at a high level of statistical significance (t=7.56, p < .01). TCSA measurements do not, of course, prove that an individual artifact was made or used as a projectile point. Yet, samples of archaeological points whose TCSA values deviate significantly from Thomas/Shott point sample should be viewed as unlikely projectile points pending the results of controlled experiments using replicas and/or wear trace and residue analysis of archaeological specimens.

A hundred or so North American stone projectile

TABLE 3. TIP CROSS-SECTIONAL AREA (TCSA) DATA AND STATISTICAL COMPARISONS FOR ARROWHEADS, DART TIPS VS. IMP AND EUP POINT SAMPLES.

	mean	sd	min.	max.	n	t-test result vs. arrowheads	t-test result vs. dart tips
CONTROLS							
Thomas Arrowheads	33	20	8	146	118	na	t= 7.56, p <.01
Thomas Dart Tips	56	20	24	94	10	t= 3.60, p <.01	t= -0.29, p= 0.77
Shott Dart Tips	59	17	20	93	30	t= 7.11, p <.01	t= 0.16, p= 0.88
All Dart Tips	58	18	20	94	40	t= 7.56, p <.01	na
IMP SAMPLES							
Skhul B Levallois points	149	82	38	413	27	t= 7.34 p <.01	t= 5.69 p <.01
Tabun C Levallois points	162	86	64	376	12	t= 5.18 p <.01	t= 4.14 p <.01
Tabun B Levallois points	148	44	62	212	9	t= 7.75 p <.01	t= 5.99 p <.01
LMP SAMPLES							
Kebara IX-XII Levallois points	133	72	30	544	295	t= 22.18 p <.01	t= 15.05 p <.01
Tor Faraj C Levallois points	113	57	20	296	142	t= 15.78 p <.01	t= 9.98 p <.01
EUP SAMPLES							
Boker Tachtit Emireh points	98	27	63	150	11	t= 7.82 p <.01	4.64 p <.01
Ucagizli B Ksar Akil points	57	20	37	102	12	t= 3.99 p <.01	t= -0.12 p= .91
Ksar Akil 16-24 Ksar Akil points	41	19	15	104	63	t= 2.66 p <.01	t= -4.69 p <.01
Ksar Akil 9-12 El-Wad points	11	4	6	18	30	t= -10.84 p <.01	t= -16.11 p <.01
Üçagizli B-F El-Wad points	39	15	5	77	67	t= 2.39 p=.02	t= -5.74 p <.01
Üçagizli B-F Backed points	43	16	20	76	19	t= 2.45 p=.02	t= -3.21 p<.01
Üçagizli F-H Obliquely Truncated points	46	12	21	63	15	t= -3.37 p <.01	t= -2.79 p <.01

points, most less than 1000 years old, are a small sample from which to judge prehistoric stone points tens, or even hundreds, of thousands of years old. That said, the factors that constrain projectile weapon effectiveness are mechanical constants; there is certainly no reason to expect earlier projectile points to preserve systemically higher TCSA values than more recent ones. As with any technology where the consequences of failure can include injury and death, the "research and development" period for Stone Age projectile technology must have been brief, much as it has been for modern-day automobile and aviation technology.

ARCHAEOLOGICAL MATERIALS

Samples of potential IMP, LMP, and EUP stone weapon armatures are available from six sites (Shea 2006b, 2009b). The IMP samples are derived from the caves of Skhul and Tabun (both in Israel). The LMP sample are from Kebara Cave (Israel) and Tor Faraj Rockshelter (Jordan). The EUP samples are from Ksar Akil Rockshelter (Lebanon) and Üçagizli Cave (Turkey). For the IMP and LMP samples, TCSA measurements were made on Levallois points—triangular flakes long thought on the basis of microwear evidence to have been used as weapon armatures (among oth-

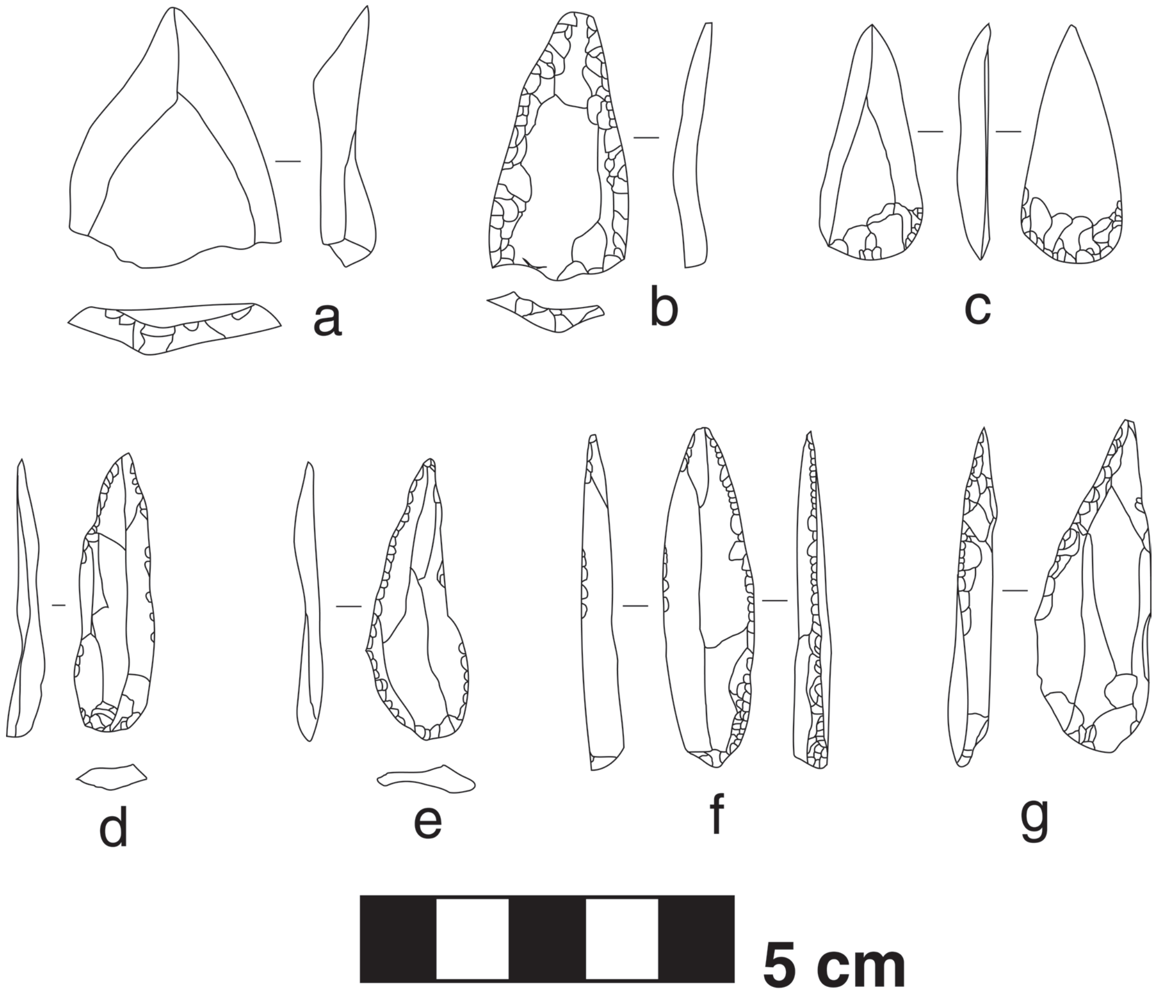

Figure 5. Stone points from Levantine IMP (a–c) and EUP (d–g) contexts. a–b: Levallois points; c: Mousterian point; d: Ksar Akil point; e: El Wad point; f: backed point; g: obliquely-backed point.

er things) by Levantine Middle Paleolithic humans (Shea 1988)(Figure 5 a–c). Depending on the typological criteria used and the extent of retouch on these tools' edges, this sample could be said to include Mousterian points as well. EUP stone points included small numbers of Levallois and Mousterian points too, but this study focuses on the more uniquely Upper Paleolithic types—Ksar Akil points, El-Wad points, backed points, and obliquely-truncated points (Figure 5 d–g). In general, these points are blades on which various amounts of backing retouch creates an elongated pointed shape. Microwear studies also suggest these EUP tools were used as weapon armatures (Bergman and Newcomer 1983).

Skhul Cave is a collapsed rockshelter in the Valley of the Caves, on Mount Carmel in Israel, excavated in 1931–1932 by McCown (1937). Skhul Level B contains Middle Paleolithic artifacts in association with the remains of early *Homo sapiens* in sediments dating to 80–130 Ka (Grün et al. 2005). Much of the Skhul Level B assemblage was discarded at the excavation site and dispersed to various museums around the world. The Skhul B point sample includes 27 artifacts from the collections of the Peabody Museum at Harvard University measured by Shea.

Tabun Cave is located several hundred meters west of Skhul overlooking the Israeli Coastal Plain. Excavated between 1927–1934 (Garrod 1937), Tabun Cave Levels B–C contain Middle Paleolithic assemblages dating to 102–165 Ka (Mercier and Valladas 2003). Nine Levallois points from Tabun Level B and 12 from Level C held in the collections of the Peabody Museum at Harvard University were measured by Shea.

Kebara Cave is located on southwestern Mount Carmel. The most recent excavations at Kebara recovered Neandertal fossils and LMP assemblages from Units IX–XII, all dating to 47–65 Ka (Bar-Yosef and Meignen 2008). Meignen provided measurements for 295 of the Levallois points recovered from these levels.

Tor Faraj is a rockshelter located in southern Jordan (Henry 2003). LMP occupations in Level C date to 69 Ka. Henry provided measurements for 142 Levallois points from Tor Faraj.

Boker Tachtit is an open-air site in the Wadi Zin (Central Negev, Israel). Four levels of "MP/UP Transitional" assemblages from this site date to at least 35–47 Ka. Measurements of eleven Emireh points from Boker Tachtit were estimated from illustrations in Marks' (1983b) monograph for the site.

Ksar Akil Rockshelter is located in the Wadi Antelias, near Beirut, Lebanon. Excavations in the 1930s and 1970s revealed a long sequence of occupations stretching from the Middle Paleolithic through the Initial Upper Paleolithic to Epipaleolithic times (Bergman and Stringer 1989; Tixier 1970). Levels 9–24 of Ksar Akil contain a rich series of Initial and Early Upper Paleolithic ("Ahmarian" and "Levantine Aurignacian") lithic assemblages dating to between 24–44 Ka (Mellars and Tixier 1989). These levels also preserve an impressive sequence of morphologically-standardized point types (Bergman 1981). TCSA data for 161 points from Ksar Akil Levels 9–24 were calculated from measurements supplied by Bergman.

Üçagizli Cave is located on the Mediterranean Coast in the Hatay region of Turkey. Since 1997, excavations at Üçagizli have uncovered a long series of Initial and Early Upper Paleolithic deposits dating to 28–41 Ka (Kuhn et al. 2009). Kuhn provided measurements used to calculate TCSA data for 122 points from Üçagizli Cave Levels B–H.

The numbers of artifact measurements from some Levantine contexts are small, and this raises some valid concerns about sample size. This problem is most acute for the IMP samples from Tabun. Vast quantities of stone tools recovered from Tabun (and Skhul) were discarded at the excavation sites. Garrod and her colleagues shipped small, selectively-curated samples of artifacts from these sites to more than a dozen research institutions. Thus, the Skhul and Tabun samples are judgmental in ways that the lithic samples from other sites discussed here are not. [Jelinek's (1982) excavations at Tabun between 1967–1973 recovered more systematic artifact samples, but these have not yet been fully described.] Yet, as shown in Shea (2006b) none of the smaller IMP samples depart significantly from the central tendency of variation among Levantine Middle Paleolithic points.

ANALYSIS AND INTERPRETATION

TCSA values for Levallois points from Levantine IMP and LMP contexts are significantly larger than those of the sample of known arrowheads and spearthrower dart tips, as measured by the results of t-tests ($p<.01$)(see Table 3; Figure 6). The TCSA values for these IMP and LMP points are essentially the same. In contrast, TCSA values for stone points from EUP contexts overlap with the values for the projectile point sample. None of these EUP point samples differ significantly (i.e., $p<.05$) from the control projectile point sample. These data suggest that EUP points would have been effective projectile points while IMP points would not. Independent studies testing replicated points as hafted projectile armatures support both these hypotheses. Replicas of EUP points work well as arrowheads (Bergman and Newcomer 1983). Levallois points used as arrowheads either bounce off animal targets or achieve only shallow penetrations (Sisk and Shea 2009). They do, however, work well as tips of experimental thrusting spears (Shea et al. 2001).

Levantine IMP, LMP, and EUP archaeological records differ in preserving evidence for the use of stone and bone-tipped projectile weapons (Shea 2006b, 2007a). This is a surprising contrast, because the use of projectile weaponry is a uniquely-derived and universally shared characteristic of *Homo sapiens* behavior. All ethnographic and human societies use complex projectile weapons, and no society has ever permanently abandoned them. If IMP humans did not use projectile technology, then this is an important behavioral difference between them and later humans, one that may explain earlier *Homo sapiens'* failure at dispersing beyond Africa and the Levant into western Eurasia, as well as later humans' success. [It may also suggest that paleoanthropologists' habit of referring to the Skhul/Qafzeh fossils as early "modern" humans may be eliding important behavioral differences between them and later humans.]

The timing of complex projectile technology's appearance in the Levant contrasts with similar evidence from other geographic regions (Shea 2006b, 2009b). On average, TCSA values for stone points from African contexts dating to more than 50 Ka are larger than the Thomas/Shott point sample. Yet, Middle Stone Age (MSA) assemblages from North, South, and East Africa all contains small numbers of carefully knapped points with TCSA values within the range of known projectile points. Backed pieces ("crescents") from pre-50 Ka African contexts also are similar to known projectile armatures from more recent contexts in terms of their ballistically-significant dimensions. The hypothesis that Subsaharan Africans were using projectile technology prior to 50 Ka is further supported by microwear and residue analysis of African MSA lithic and bone points (d'Errico and Henshilwood 2007; Lombard 2005; Lombard and Pargeter 2008). How much earlier such complex projectile weapons were in use in Africa remains unknown. The oldest generally-accepted evidence concerns thinned bifacial points and backed pieces from South African Middle Stone Age contexts, most of which are younger than 70 Ka (Lombard and Phillipson n.d./in review; Villa et al. 2009b).

European stone point samples dating to more than 50 Ka and including Mousterian points and bifacially-thinned "leaf points" all preserve TCSA values significantly larger than those of known projectile points (Shea 2006b). European Upper Paleolithic stone points' TCSA values do not differ significantly from those of arrowheads and spearthrower dart tips. These stone points are accompanied by a wide range of bone/antler projectile points as well (Knecht 1994). Such technological diversity is exactly what one sees in the traditional subsistence technology deployed by hunter-gatherers who depended heavily on the use of projectile weaponry to secure fat and protein from a wide range of animal prey (Oswalt 1973). It is a stark contrast with the limited range of putative stone weapon armatures from European Middle Paleolithic contexts.

DISCUSSION

The TCSA evidence from the Levant has important implications for hypotheses about the local vs. exotic origins of Levantine EUP projectile technology, Neandertals' and other hominins' apparent failure to develop complex pro-

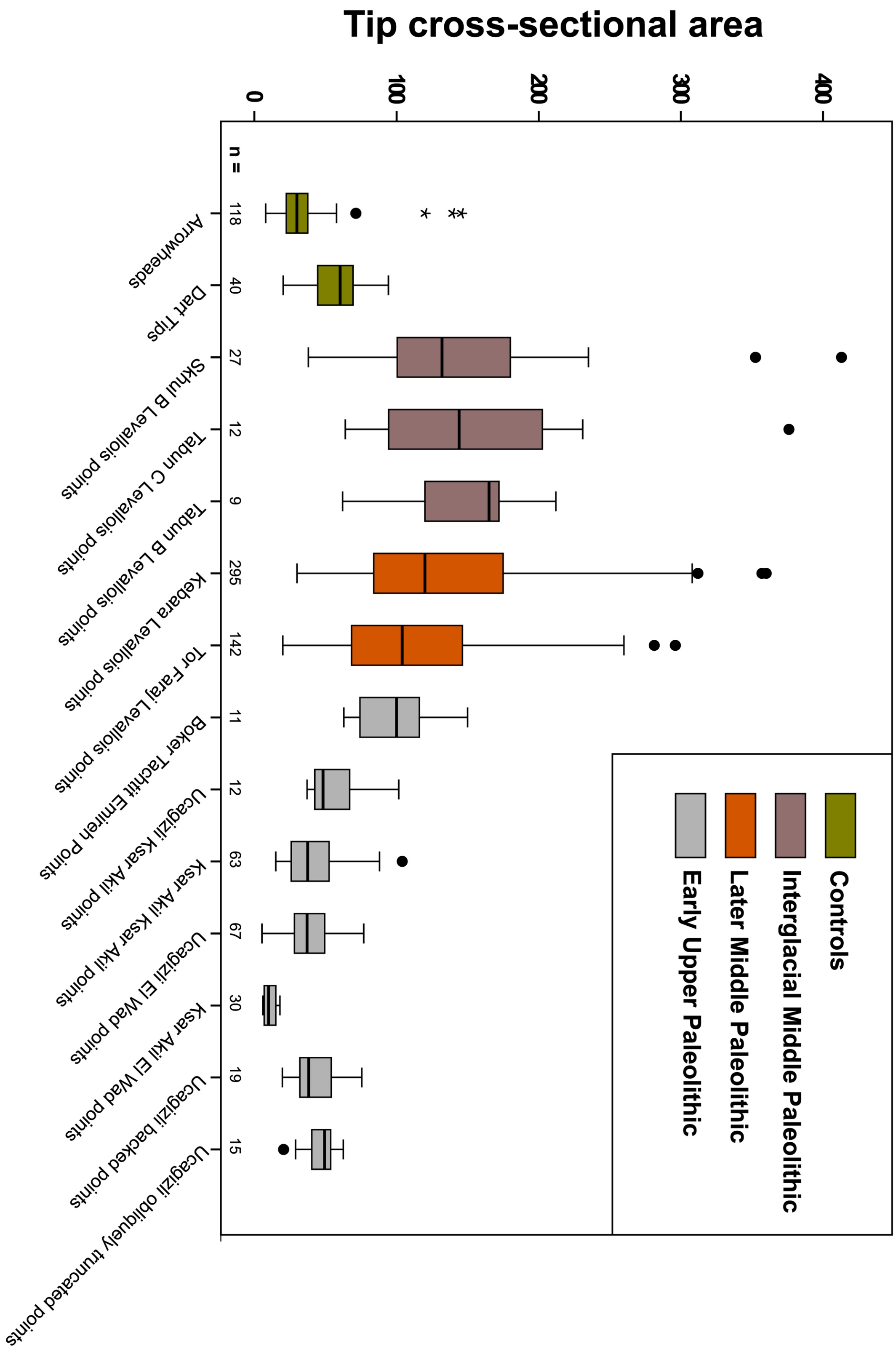

Figure 6. Graph showing variation in tip cross-sectional area values for Levallois points from IMP contexts and various stone points from EUP contexts.

jectile technology, and the relationship between complex projectile technology and other hypothetical factors in human dispersal.

ORIGINS OF LEVANTINE EUP PROJECTILE TECHNOLOGY

In considering the origins of Levantine EUP projectile technology, we can entertain three rival hypotheses, indigenous origin, diffusion, and the dispersal to the Levant of populations already using complex projectile technology.

Late Pleistocene aridity could have packed Levantine LMP human populations into refugia along the Mediterranean coast, creating incentives for niche broadening through the use of complex projectile technology. But, the case for an indigenous Levantine origin of projectile technology is not particularly strong. Levallois and Mousterian points from IMP and/or LMP assemblages do not show any kind of a trend over time towards lower TCSA values (Shea 2006b). Emireh points (pointed flakes and blades with basal thinning), an EUP stone point type with plausible LMP precursors (Marks 1983a), preserve TCSA values larger than recent projectile armatures (Shea 2006b: 834). Despite Emireh points' value as indicators of cultural continuity across the Middle-Upper Paleolithic "Transition" in the Levant, their morphological variability does not support the hypothesis of an indigenous Levantine origin for complex projectile technology. Perhaps most tellingly, LMP contexts from Kebara Cave that preserve evidence for over-hunting gazelle and deer (Speth and Clark 2006) do not feature either TCSA or microwear evidence for a shift towards complex projectile technology (Plisson and Béyries 1998; Shea 2006b). It is certainly possible that EUP humans developed complex projectile technology with no precursors in earlier local technological strategies, but it is unclear how one would go about testing this hypothesis directly. Indeed, an origin without local antecedents would run counter to other lines of archaeological evidence suggesting cultural continuity across the Middle-Upper Paleolithic "Transition" in the Levant (Belfer-Cohen and Goring-Morris 2007; cf. Hovers 2009; Shea 2008).

There is growing evidence for the use of complex stone- and bone-tipped projectile weapons in Equatorial and Subsaharan Africa between 50–100 Ka, or even earlier (Brooks et al., 2006; d'Errico and Henshilwood 2007; Lombard and Pargeter 2008; Lombard and Phillipson in press; Shea 2009b; Waweru 2007). This period appears to have witnessed increasing aridity (Barham and Mitchell 2008; Willoughby 2007). Sediment cores from Lake Malawi have been interpreted as indicating recurring megadroughts (Cohen et al. 2007; Scholz et al. 2007) and the formation of refugia the southern Cape, the Ethiopian highlands, and the immediate environs of major East African lakes and rivers (Basell 2008; Brandt 2006). Other studies suggest an overall reduction of vegetation throughout the subcontinent (Cowling et al. 2008). Whether or not such refugia actually existed, the periodic episodes of hyper-aridity that repeatedly afflicted African humans from Plio-Pleistocene times onwards (Trauth et al. 2007), combined with equatorial Africa's rich biodiversity, likely created strong selective pressures for versatile subsistence strategies. Much of the humanly-edible animal biomass in equatorial African forests, woodlands, and savannas are species that are large, dangerous terrestrial mammals (e.g., elephant, Cape buffalo), aquatic (e.g., fish, crocodile, hippopotamus), arboreal (e.g., monkeys), or nocturnal (e.g, bush pig)(Estes 1991). Recent African humans use complex projectile weaponry, along with nets, traps, and other technological aids to prey on these species. It seems reasonable to imagine that Pleistocene African humans developed complex projectile weaponry to aid in subsistence versatility, as a means by which their niches could have been broadened or narrowed as circumstances required. Why projectile weaponry may have developed so much earlier in Africa than in the Levant may simply reflect larger African human population sizes (Powell et al., 2009). All other things being equal, the incentives for niche broadening are likely to have been more acute for larger populations than for smaller ones. Even if complex projectile technology developed as early in the Levant as in Africa, the Levant's small size and correspondingly small human populations may have worked against it becoming a stable component of subsequent human adaptive strategies. This evidence and these considerations suggest diffusion and dispersal are at least as likely as independent invention in explaining the appearance of complex projectile technology in the EUP Levant.

The case for the diffusion of projectile technology to the Levant is not strong. Ksar Akil points, El Wad points, and other Levantine EUP points do not demonstrably occur at earlier dates in other regions adjacent to the East Mediterranean Levant (Bar-Yosef 2000). The foliate points and backed pieces that are among the most plausible of African Middle Stone Age projectile points are not found in Levantine EUP contexts. It is not impossible that technical knowledge of complex projectile technology's delivery systems, such as the spearthrower and/or the bow and arrow, diffused to the Levant separately from information about the armatures for these weapons. On the other hand, there are few well-documented examples of such incomplete diffusion of technical know-how in pre-industrial contexts.

The case for dispersal of projectile-using humans to the Levant suffers from some of the same weaknesses as the diffusion hypothesis; namely, the lack of an artifactual "trail" linking the EUP of the Levant to another region. Fortunately, artifacts are not the only evidence for population dispersal. The hominin fossil and recent human genetic records (Grine et al. 2007; Kivisild 2007) strongly support the hypothesis that there was a dispersal of *Homo sapiens* populations from Africa and southern Asia to western Eurasia at around the same time as EUP assemblages began to be deposited. That the specific forms EUP projectile armatures took do not replicate African precursors does run counter to models for detecting "migration" derived from recent contexts (Clark 1994), but this is not necessarily a crucial flaw. Populations dispersing into new territories do develop novel artifact forms unknown in their donor region. For example, it is beyond serious scientific dispute that the

Americas were first populated by humans dispersing there from northeastern Asia, and yet few specific artifact-types connect these two regions (Meltzer 2009). There are technological parallels between terminal Pleistocene lithic assemblages from northeastern Asia and New World Paleoindian assemblages; but, distinctive Clovis points and other "fluted" points appear to have been a uniquely American development.

At present, the most satisfactory explanation for the appearance of complex projectile technology in the Levant is that it was brought there by dispersing populations of African humans. Only Neandertal fossils are known from LMP contexts and only *Homo sapiens* fossils are known from EUP contexts. Taking this evidence at face value suggests that projectile technology arrived in the Levant as part of the same hominin replacement/turnover event that occurred throughout Eurasia 45–25 Ka.

WHY NO NEANDERTAL PROJECTILE TECHNOLOGY?

Why complex projectile technology was not already in use by Levantine humans, Neandertals, and early *Homo sapiens* alike, remains an enigma. For more than a century, archaeologists have searched in vain among European Middle Paleolithic stone tool assemblages for stone and bone tools comparable to the projectile armatures used by recent humans. Cold Eurasian habitats would have required Neandertals and their evolutionary precursors to obtain much of their dietary fats and proteins from animal prey (Marean 2007). Stable isotopic analysis of Neandertal fossils suggests they did precisely this. The carbon and nitrogen isotopes of Neandertal collagen look like those of carnivores (Bocherens 2009). The wide swings of the Pleistocene climatic pendulum must have pushed Eurasian Neandertals into ecological refugia (e.g., southern Iberia, Italy, the Balkans, and the Levant)(Finlayson 2004), in which they would have faced precisely the same incentives to broaden their niche as African humans did. And yet, no conclusive evidence of Neandertal projectile technology survives in the archaeological record.

Neandertals hafted stone tools onto spears, but these points are so large that they must have been attached to thick, heavy thrusting spears or hand-cast spears (Shea 1997; Villa et al. 2009a). Unlike contexts associated with *Homo sapiens* projectile point usage, the occurrence of these points is not systemically correlated with parallel evidence for either increased exploitation of smaller prey or more specialized predation on larger game (Kuhn and Stiner 2001).

Many of the most plausible candidates for Neandertal projectile points, including Chatelperronian points, "leaf points," and various backed pieces occur in very late Middle Paleolithic or in "transitional" contexts immediately preceding regional first appearance dates for *Homo sapiens*. As Bar-Yosef (2007) has recently cautioned, we have to remain alert to the possibility that these points were made by *Homo sapiens* populations moving at the leading edge of human dispersal. An alternative perspective might see these artifacts as reflecting either an independent, if belated, development of projectile weaponry or diffusion of the projectile technology from dispersing *Homo sapiens* populations to indigenous Neandertals. Whatever one thinks about these artifacts, they do not explain the absence of projectile technology in the period of Neandertal evolution in western Eurasia prior to 50 Ka.

Neither insufficient intelligence or nor inadequate biomechanics are plausible explanations for the absence of Neandertal technology. Projectile weapons like the bow and the spearthrower require understanding and control of some fairly complex mechanical principles, particularly tensile stress and centrifugal force, but also fiber and adhesive technology. Nonhuman primates competently use wood subjected to tensile stress in tool use and are reasonably good at aimed throwing (McGrew 2004; Povinelli 2003). Thus, it is difficult to believe these physical and mechanical principles were beyond Neandertal comprehension (Hayden 1993; Speth 2004b). The 400,000-year-old wooden spears from Lehringen and Schöningen show that Neandertals' immediate ancestors, European *Homo heidelbergensis*, understood how to use these principles to make effective subsistence aids. It is difficult to imagine selective pressures that would remove such technical know-how in the course of Neandertal evolution.

It has long been argued that relatively shorter arms may have made Neandertals less effective spear-throwers than longer-limbed *Homo sapiens* (Brues 1959). While this hypothesis may explain why Neandertals might not have been as good at using projectile weapons as *Homo sapiens*, it does not explain why Neandertals and their ancestors did not devise projectile weapons on their own long before humans dispersed from Africa into western Eurasia. Longer arms and legs confer some advantage in throwing, but a competent craftsman can easily compensate for this by adjusting the shape of a bow or the length of a spearthrower.

Currently, one of the most plausible explanations for Neandertals' failure to develop complex projectile technology involves energetic constraints and time-budgeting (Torrence 1983). Neandertals are thought to have had higher daily caloric requirements than *Homo sapiens* (Churchill 2006; Sorenson and Leonard 2001). If so, this must have influenced how they integrated technology with their subsistence and land-use strategies (Verpoorte 2006). There are risks in extrapolating from modern-day survival techniques to prehistoric human adaptations, but there are also valuable insights to be gained into the constraints of projectile weapon use. The best military and civilian survival manuals emphasize finding plant and small animal food sources that do not require complex procurement technology (US Army 1994; Brown and Morgan 1983; Hawke 2009; Olsen 1973). Someone who knows how to make a simple bow or spear-thrower can do so in an hour or less (Allen 1994). But, such expedient weapons rarely work well or long enough for the person who made them to develop skill in their use and to recoup the calories spent in making them. Functioning ethnographic bows, arrows, spearthrowers, and darts are complex instruments that require hours of production, maintenance, and practice. The time these tasks require has to come from some other realm of activity. We suggest that Neandertals' high daily caloric requirements left them with insufficient time to develop projectile weapons as effective as those our ancestors deployed at more or less the same time in contiguous geographic areas. That the most plausible Neandertal weapon armatures are flaked stone points that can be knapped in a few seconds, and not carved bone/antler points that require hours of production effort, underscores the argument that time was a significant constraint on Neandertal technological strategies.

Energetic constraints also shed light on one of the more puzzling aspects of Neandertal tool use, why they were apparently able to make stone-tipped spears but not stone- or bone-tipped projectile weapons. Stone points improve the penetrating power of simple wooden spears and they increase hemorrhage in a wounded animal, typically a large marine or terrestrial mammal (Ellis 1997). They have less value against small, mobile targets, where misses and tip breakage are more likely. Neandertal stone spear point production may reflect a particular Neandertal kind of "intensification," a strategic effort to improve hunting success by improving the reliability of their hunting weapons against the large terrestrial mammals that were the mainstays of their previous subsistence adaptation. If Neandertal daily energetic requirements were relatively high compared to those of *Homo sapiens*, a strategy of responding to foraging deficits by increasing dependence on plant foods and smaller game may have yielded insufficient returns. Many of the final Middle Paleolithic and "Transitional" assemblages associated with Neandertals in Europe differ from their precursors in preserving pointed, symmetrical stone points and backed pieces (Teyssandier 2008). These points include Chatelperron points, Uluzzian backed pieces, Central and East European "leaf points" (*Blattspitzen*), and arguably Emireh points. If these points were "reliability-enhancing" weapon armatures, as is generally supposed, then the increased technological effort allocated to producing them may reflect a Neandertal strategy of coping with foraging deficits not by pursuing new prey, but rather by increasing their effectiveness of their existing technological aids. As such, Neandertal stone spear point production may be evidence of populations whose longstanding subsistence strategies were beginning to fail them. Increased point production in Levantine Later Middle Paleolithic contexts at Kebara Cave is correlated with faunal evidence for over-hunting medium-sized game (deer and gazelle) (Speth 2004a). It would be interesting to know if this is a strictly Levantine phenomenon or if it is part of a broader pattern among Neandertal subsistence and technological strategies.

PROJECTILE TECHNOLOGY, POPULATION GROWTH AND SYMBOL USE

In proposing that projectile weaponry played a key role in human dispersal after 50 Ka, we are not arguing that it operated to the exclusion of other factors, such as symbolism and demographic pressure.

Among recent humans, complex projectile weaponry is often extended from subsistence into the social realm, to injure, intimidate, and kill social and economic rivals. Therefore, one would expect habitual prehistoric human projectile weapon usage to have increased selective pressure for more common, effective, and durable symbol use, if only to improve methods for identifying friends, foes, and potential allies at a safe distance. The proliferation of bead production and other evidence for personal adornment seen in western Eurasia after 50 Ka may reflect a social environment created by the habitual use of complex projectile weapons.

A link between complex projectile weapon use and exosomatic symbolic behavior also could explain the weak evidence for Neandertal production of symbolic artifacts. Archaeological contexts associated with Neandertals and *Homo heidelbergensis* feature evidence plausibly referable to symbol use, such as the production and use of mineral pigments, repetitive markings on bone and other media, long-distance transport of raw materials, and (arguably) mortuary practices. And yet, the sum total of all such evidence is but a fraction of that recovered from any single European Upper Paleolithic site. It is improbable that Neandertals and earlier humans lacked the ability to make and use exosomatic symbols. Neandertal DNA preserves the FOXP2 "language gene" (Krause et al. 2007), suggesting that selective pressure for speech long predates the Neandertal-*Homo sapiens* evolutionary divergence in the Middle Pleistocene. It is more likely that, absent complex projectile weaponry, there was only weak selective pressure for *H. heidelbergensis*, *H. neanderthalensis*, and other Middle-Late Pleistocene hominins to create durable, complex, and "archaeologically-visible" exosomatic symbols comparable to those deployed by *Homo sapiens* after 50 Ka.

Invoking demographic change as the motor cause of human dispersal is almost trite, for how could it be otherwise? Species with stable population sizes and those experiencing population reductions do not have the demographic resources to expand their range. On the other hand, a broadened, stabilized, and flexible ecological niche created by the use of projectile weapons in subsistence would likely create ideal conditions for population growth, and subsequently, demographic pressures for dispersal.

The hypothesis that projectile weapon use was a principal force in human dispersal after 50 Ka does not in and of itself refute significant roles for symbol use and demographic change. It may not be any one of these three factors alone that underwrote human dispersal and evolutionary success, but rather the synergy among them. The point one should take away from this paper is not that we owe our current global dominion to projectile technology, but rather it is that the significance of projectile technology has been underestimated in models for the 50 Ka human dispersal.

The hypothesis that projectile weaponry was a key factor in the 50 Ka dispersal is not without problems. Criteria for identifying prehistoric projectile points need to be improved. Morphometric comparisons can suggest possible tool functions, but they do not prove them. Experimental use of replicated stone and bone points is a rich source of interpretive principles for the archaeological record, but there need to be many more experiments with strong controls and adequate documentation. Lithic microwear and residue based analyses of stone tool function yield useful insights, but a seemingly irreducible subjective component to wear interpretation and judgmental sampling methods limit their scientific value.

The antiquity of projectile weaponry in Africa is poorly understood. That many stone and bone points dating to more than 50 Ka were projectile armatures is a belief broadly shared among African prehistorians. Yet, few of these artifacts have been subjected to the kind of morphometric, microwear, and residue analyses needed to test hypotheses about their functions (Lombard and Phillipson in press).

Finally, human dispersal and first appearances of evidence for projectile technology are reasonably well-documented in Europe and temperate western Asia. The evidence is less clear for South Asia and Sahul (Pleistocene New Guinea and Australia). Until this record is better understood it remains possible that we are under- or over-estimating the behavioral variability involved in this dispersal.

CONCLUSION

Homo sapiens originated in Africa by at least 195 Ka. The first evidence for our ancestors' permanent dispersal outside of Africa dates to around 45 Ka, a difference of more than 150,000 years. Why did it take so long for *Homo sapiens* to get out of Africa? Evidence from the East Mediterranean Levant, the only permanent land-bridge between Africa and Eurasia, suggests that by 50 Ka *Homo sapiens* had got as far as they could without projectile technology.

Colder Ice Age Eurasian habitats required hominins to procure greater proportions of their dietary fats and protein from animal sources. Fortunately, large Eurasian mammals store body fat to a greater extent than tropical mammals of similar size (Speth and Spielmann 1983). Neandertals' strategic response to cold Eurasian climate appears to have been specialized hunting of large terrestrial fauna with minimal technological assistance. This strategy was probably a response to high energetic requirements and small group sizes. Levantine IMP human subsistence strategies appear to have been broadly similar to LMP Neandertal ones, and they were probably vulnerable to similar disruptive forces. Droughts and rapid shifts to colder conditions would have seriously limited IMP humans' ability to disperse (Finlayson and Carríon 2007). The fossil record for IMP humans ends ca. 75–65 Ka, at more or less the same time as the abrupt onset of glacial conditions (Shea 2008). Like Vinland, Roanoke, Botany Bay, and other failed colonial enterprises of recent history, the IMP dispersal into the Levant was likely a "false start" in our species' global geographic dispersal (Shea and Bar-Yosef 2005).

Explaining the origins of projectile technology is not a realistic scientific goal. Preservation biases alone guarantee that any hypothesis about the origins of largely organic projectile technology will be nearly impossible to test with archaeological evidence. Rather, what needs to be explained is why projectile technology changed from an archaeologically invisible phenomenon before 50–100 Ka to one that became both ubiquitous and integral to human adaptive success afterwards. As matters stand today, the oldest evidence for the increased "archaeological visibility" of complex projectile technology comes from Equatorial and Subsaharan Africa. In these regions, complex projectile weapons like the bow and arrow, and spearthrower and dart, probably developed as aids to economic intensification and niche broadening. In Subsaharan Africa (and in the Asian tropics as well), fish and other small mammals are rich sources of protein and fat, sources that were historically exploited by the use of projectile technology, as well as traps and nets (Inskeep 2001; Maclaren 1958). That recent humans need technological aids in order to exploit such prey systematically and efficiently suggests that they were probably relatively low-ranked food sources for early humans. That is, they were foods small groups of humans avoided when other prey requiring less energetically costly technological aids were available. Selective pressure to intensify subsistence and exploit these low-ranked foods may have resulted from "population packing" during Late Pleistocene arid periods, but earlier origins and other causes cannot be ruled out at present. As humans expanded their geographic range into western Eurasia, complex projectile technology allowed them to maintain the broad, but flexible ecological niche they had built for themselves in Africa (Marean 2007).

Though conclusive evidence for competitive encounters between Neandertals and *Homo sapiens* remains controversial, many paleoanthropologists believe such encounters occurred (Shea 2003b; Banks et al. 2008; Conard 2006; Finlayson and Carríon 2007). If competition did occur, projectile technology would have conferred decisive advantages. It would have enabled humans to exploit the mainstays of Neandertal subsistence, large terrestrial mammals, at considerably lower risk of failure or injury. It would have allowed humans to efficiently exploit additional food sources that Neandertals left largely alone, such as aquatic mammals, small game, birds, and fish. In effect, *Homo sapiens* would have replaced Neandertals largely through a process of niche "envelopment," by exploiting the same resources more efficiently and by exploiting additional resources that were too costly for their Neandertal competitors to exploit effectively (O'Connell 2006). We do not have evidence for coalitionary violence between Neandertals and humans (cf. Churchill et al. 2009), but if there were such encounters, projectile weaponry would have provided key tactical advantages for populations adept at using it.

Projectile technology is an enabling technology. It enabled *Homo sapiens* to become the ultimate ecological generalists, conferring adaptive advantages over more specialized hominins, and allowing our species to disperse to western Eurasia. Tempting as it may be to see such an evolutionarily momentous result deriving from an equally momentous cause, from a prehistoric "Human Revolution," we are skeptical about any such a conclusion.

First, in the greater scheme of things, dispersal into western Eurasia was not that significant. For most of the last million years, Europe and adjacent parts of western Eurasia have been harsh and unforgiving habitats, probably home to no more than a few hundred thousand hominins at any given moment, and they remain human "population sinks." Even today, the human population growth rates of many countries north of the Alps are sustained by immigration from more southerly climes. Dispersal to the warmer parts of southern and eastern Asia, Sahul, and the Americas were more significant for our species' overall population size and evolutionary stability. That we know so little about *Homo sapiens* dispersal into these regions compared to Europe is among the greatest ironies in contemporary human origins research.

Secondly, we do not yet know whether our species' present capacity for wide, technologically-mediated, behavioral variability, including projectile weapon use, evolved during the course of *Homo sapiens* evolution, or if it was inherited from ancestral hominins (Potts 1998). Hominins have been practicing technologically-assisted subsistence strategies since Early Pleistocene times, if not earlier. The increasing use of projectile technology in Late Pleistocene times, and its role in our species' dispersal, could merely reflect historically-contingent shifts in selective pressure on human subsistence and technological strategies. The argument that the humans who left Africa 50 Ka were different in some essential way from the earliest *Homo sapiens* populations or from their immediate evolutionary precursors is more an entrenched assumption than an hypothesis that has withstood rigorous scientific testing (Shea in press).

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