Fall 2017

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In an accompanying paper (*Journal of Anthropological Research* 73(2):149–80, 2017), the authors assess current archaeological and paleobiological evidence for the early Neolithic of China. Emerging trends in archaeological data indicate that early agriculture developed variably: hunting remained important on the Loess Plateau, and aquatic-based foraging and protodomestication augmented cereal agriculture in South China. In North China and the Yangtze Basin, semisedentism and seasonal foraging persisted alongside early Neolithic culture traits such as organized villages, large storage structures, ceramic vessels, and polished stone tool assemblages. In this paper, we seek to explain incipient agriculture as a predictable, system-level cultural response of prehistoric foragers through an evolutionary assessment of archaeological evidence for the preceding Paleolithic to Neolithic transition (PNT). We synthesize a broad range of diagnostic artifacts, settlement, site structure, and biological remains to develop a working hypothesis that agriculture was differentially developed or adopted according to "initial conditions" of habitat, resource structure, and cultural organization. The PNT of China is characterized by multiple, divergent evolutionary pathways: between the eastern and western parts of North China, and between and the Yangtze Valley and the Lingnan region farther south.

**Keywords:** origins of agriculture, China, foraging intensification, evolution, Paleolithic to Neolithic transition

The origins of agriculture lie in an archaeologically ambiguous zone that bridges both Paleolithic and Neolithic lifeways (e.g., subsistence, technology, and site organization). Until recently, studies of the transition from the Chinese Upper Paleolithic (UP) to the Neolithic have focused on emergent Neolithic traits such as pottery and domestication. Therefore, to contribute to recent research on this subject (Barton et al. 2009; Bettinger et al. 2007, 2010; Chen 2013; Liu 2008) we use a strategy of working from the more robust and better-known Neolithic record toward what we do not know: the preceding transitional period (Chen and Yu 2017).[1]

Early Neolithic data from North China and the Yangtze River basin show two interesting evolutionary trends. The first is a change of habitat in which the earliest farm-

Submitted February 20, 2016; accepted September 26, 2016; published online May 30, 2017.
*Journal of Anthropological Research* (Fall 2017).  0091-7710/2017/7303-0002$10.00

ers moved from topographically diverse ecosystems such as the hilly flanks or margins of drainage basins downslope to piedmonts and floodplains. The second is the emergence of a suite of material traits, including growing numbers and size of sites; internal organization; robust architecture; features such as ditches, dams, storage pits, and graveyards; a proliferation of pottery types; and polished stone tool assemblages indicative of woodworking. Alongside this apparent cascade of changes, however, echoes of the previous foraging lifeway can still be seen. The archaeological record shows that seasonal foraging continued through the early Neolithic, marked by semisedentary settlement patterns and storage facilities with caches of tools and food intended for later use (Chen and Yu 2017). Yet we still know little about the period that followed the Late Upper Pleistocene and preceded the early Neolithic. The transitional character of the archaeological record, difficulty in diagnosing cultural stages, and a history of research specialization in either the Paleolithic *or* the Neolithic are important factors.

Fortunately, the roster of Chinese archaeological data for the last foraging and first farming societies is growing, and we have an unprecedented opportunity to frame and test expectations for the initial conditions that led to agricultural origins. This paper revisits the better-known early Neolithic period by summarizing new data about cultural developments that occurred between the Upper Paleolithic and primordial Neolithic agriculture in two major habitats: North China and the Yangtze Valley. We will also touch upon human behavioral ecology models that are germane to evaluating labor effort, costs to mobility, and decision-making at the boundary between foraging and food production (Cohen 2009; Gremillion 1996, 2002; Gremillion and Piperno 2009; Kramer and Greaves 2014; Piperno and Pearsall 1998; Smith 2001; Winterhalder and Kennett 2006).

## DESCRIBING AND DEFINING THE PALEOLITHIC-TO-NEOLITHIC TRANSITION

The established criteria for identifying the early Neolithic provide a useful platform for exploring the less-well-known period when intensified foragers were experimenting with domestication (Gremillion 2002; Winterhalder and Kennett 2006). However, to avoid projections of the Neolithic onto the preceding period and to facilitate independent evolutionary comparisons, we propose a distinct chronological and evolutionary stage: the Paleolithic to Neolithic transition (PNT). Our definition of this somewhat murky period uses existing archaeological characteristics and terminologies and is in agreement with most Chinese researchers (e.g., IA-CASS 2010; Yan 2008), who have determined that the PNT occurred across a wide range of habitats between ca. 20,000 and 8,500 BP (more field data will change this, although we expect the lower date to hold).

Given that archaeological culture stages stem empirically from regional patterning in the archaeological record, we note that even the most widely used concepts such as Paleolithic and Neolithic are not universally adopted (as in the case of African prehistory). Thus, the PNT should not be confused with the "Mesolithic" (sensu Price 1987), which originated in European archaeology and was originally defined as a culture-historical stage between the Paleolithic and the Neolithic. The Mesolithic was later conceptualized as a distinctive set of complex foraging adaptations in resource-rich temperate regions such as northwestern Europe, Jomon period Japan, the Northwest Coast of North America, and coastal Peru. Although aquatic-focused foraging did occur during the PNT in China (in the northeast as well as south of the Nanling Mountains in the Lingnan region) and persisted through the early Neolithic along the southeast coast, we argue that the Mesolithic concept does not apply to the cultural sequence in North China and the middle and lower Yangtze Valley. Thus we define the PNT in China as the evolutionary stage during which intensified foraging coexisted with and developed into the earliest farming from ca. 20,000 to 8,500 BP.

### *PNT Beginnings*

The end of the Chinese PNT is demarcated by the emergence of the early Neolithic, but a beginning date for the PNT is uncertain because of the ambiguous and dispersed archaeological evidence. We will therefore set a likely range of early dates using both archaeological and environmental data. The termination of the Last Glacial Maximum (LGM) brought warming climates, rising sea levels, and faunal and vegetational changes. Microblade technology reached its peak, then gradually declined in the center of North China, although it continued until the historical period in other areas (e.g., Yi et al. 2013). Evidence for the protodomestication of plants comes later (Zhao 2006, 2011), but genomic evidence for intentional, selective breeding of dogs indicates that UP foragers were capable of manipulating behavior and reproduction of animals to establish a mutualistic—later, domesticated—relationship by 16,000–30,000 years ago (Germonpré et al. 2012; Larson et al. 2012; Pang et al. 2009; Savolainen et al. 2002). Thus the groundwork for selective breeding to enhance desirable traits in organisms was already well-established by foragers of the UP.

At the end of the LGM about 19,000–18,000 years ago, pottery made its first appearance at Xianrendong (Wu et al. 2012) and ca. 2,000 years later at the Yuchanyan site (Boaretto et al. 2009; Yuan 2013). Grinding tools such as mortars and pestles and finely retouched or edge-polished adze-like tools are a culture trait of the early PNT and are mostly found in North China, such as at Mengjiaquan (Hebei 1991; Xie et al. 2006), Longwangchan (IA-CASS and Shaanxi PIA 2007; Zhang et al. 2011), and Xiachuan (Wang et al. 1978) (Figure 1).

The increasing use of AMS radiocarbon dating and paleoethnobotanical methods such as flotation and phytolith analysis is expanding the sample of PNT sites and occupation levels. Recent discoveries include Lijiagou (Beijing 2011; Zhenzhou 2011) and Shizitan (Linfen 1989; Shizitan 2002, 2010, 2011; Yuan et al. 1998). Further, archaeological data have been published after lengthy delays from sites such as Nanzhuangtou (Baoding 1992, Hebei 2010) and Xianrendong and Diaotonghuan (the latter is only about 1 km from the former; Beijing 2014). Some recently excavated sites have been recorded using detailed new field techniques, leading to their designation

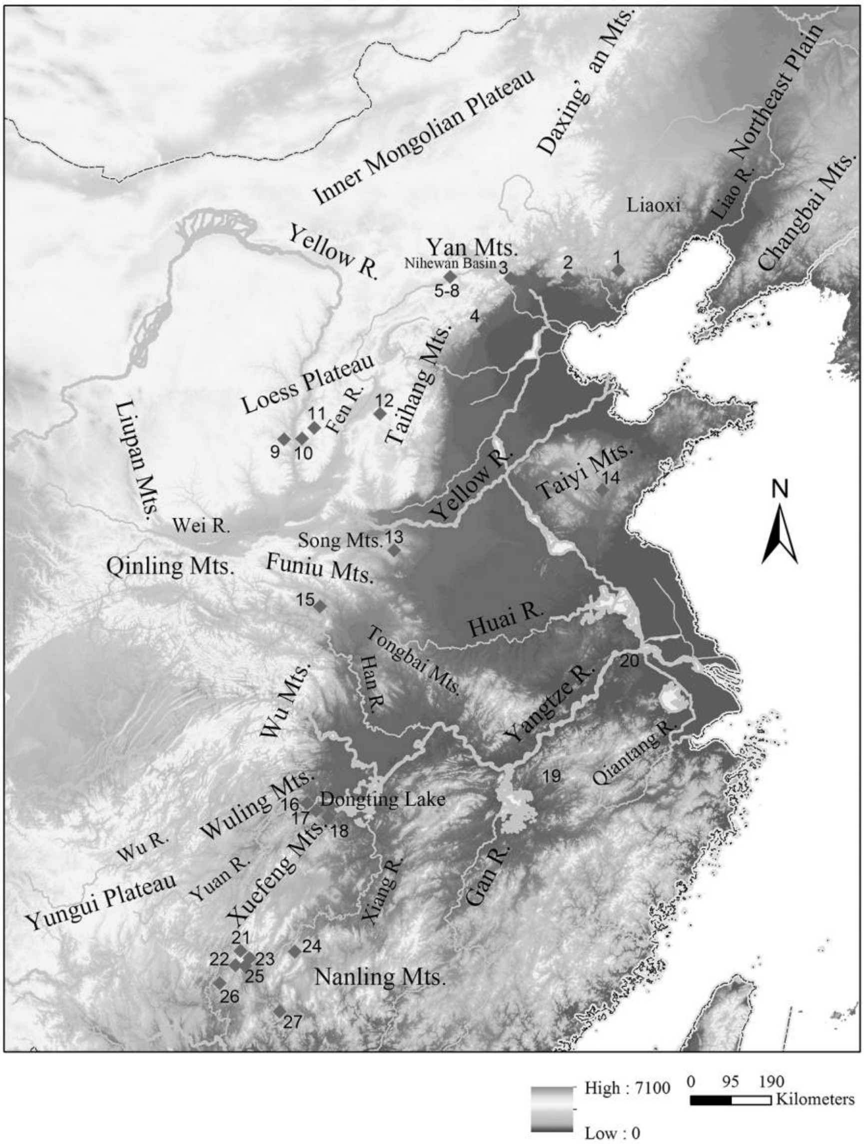


Figure 1. Locations of major sites of the Chinese PNT: 1=Nanzhuangtou; 2=Zhuannian; 3=Donghulin=4, Lijiagou; 5=Bianbiandong; 6=Kengnan; 7=Yujiagou; 8=Ma'anshan; 9=Hutouliang; 10=Mengjiaquan; 11=Jijitan; 12=Xueguan; 13=Shizitan; 14=Xiachuan; 15=Longwangchan; 16=Yuchanyan; 17=Huadang; 18=Songjiagang; 19=Zhuma; 20=Xianrendong*; 21=Shenxiandong; 22=Zengpiyan; 23=Miaoyan; 24=Dayan; 25=Liyuzui; 6=Bailiandong; 27=Huangyandong

*Diaotonghuan is about 1 km from Xianrendong.

as PNT rather than LUP or early Neolithic. Stratigraphic sequences representing the LUP and PNT have been found at sites such as Lijiagou (Wang et al. 2015) and Shizitan locality 9 (Shizitan 2010). Although PNT archaeological data are still sparse relative to the early Neolithic and even the LUP, these improvements offer the best opportunities yet for sketching the outlines of the transition.

Table 1 lists major sites of the PNT and LUP and includes three sites that share habitat characteristics with the middle Yangtze Valley, although they are not technically within its boundaries—Zengpiyan, Miaoyan, and Dayan in Guangxi Province, which are generally assigned to the Lingnan region (a part of eastern and coastal South China) rather than the middle and lower Yangtze Valley.

### *Three Descriptive Levels for the PNT*

In the transition from foraging to farming, the most obvious change is from mobile living to sedentary settlement. Different ecological niches, subsistence resources, and technologies are required for food production, each exhibiting distinctive archaeological patterning. First, at the assemblage level, innovation and invention of new artifact types such as pottery, polished stone tools, and grinding tools for plant seeds may be associated with changing preferences for lithic raw materials. Second, at the site level, different patterns of social organization are evident in site types, distribution, and internal spatial organization reflecting the functional requirements of agricultural living (residences, storage facilities, defense features, etc.). Third, at the level of subsistence and resource utilization, foragers may have greater niche breadth reflected by more richness in wild resource diversity, whereas agriculturalists depend on a mix of wild and domesticated taxa with the latter eventually predominating.

During the PNT stage we predict that the transition between foraging and food production should be reflected in the coexistence of archaeological materials representing both types of subsistence at the assemblage level. Simply put, diagnostic features of LUP artifact assemblages and site organization should decline over time, while Neo-

Table 1. Major sites of the PNT and LUP

| | | Major Sites | | | |
|---|---|---|---|---|---|
| | | South China | | North China | |
| Age (BP) | Stage | Yangtze Valley | Lingnan Region | East of Taihang Mts | Loess Plateau |
| ca. 15,000~8,500 | PNT | Yuchanyan, Xianrendong | Zengpiyan, Miaoyan, Dayan | Zhuannian, Donghulin, Nanzhuangtou, Yujiagou, Ma'anshan, Lijiagou | Shizitan, Xiachuan, Xueguan |
| ca. 24,000~15,000 | LUP | Lower Bashidang, Shiligang, Yan'erdong Cave | | Xishi, Longwangchan, Shizitan, Xiachuan | |

lithic traits should increase. As for food resources, we expect transitional assemblages to display a shift from wild to domesticated forms, with selection for desired characteristics being reflected in the faunal and botanical record. Table 2 lists emergent traits from sites in North China (east and west) and South China, including the middle and lower Yangtze Valley.

## CHANGES IN ARTIFACT ASSEMBLAGES

### *Containers*

Pottery is an important marker trait in PNT sites of the middle and lower Yangtze Valley and North China. Global perspectives on the origin of pottery (summarized in Rice 1999; see also papers in Jordan and Zvelebil 2009) range from utilitarian to costly signaling or feasting displays, yet most acknowledge that the appearance of pottery correlates with intensification of resources. The causes of foraging intensification have long been debated, ranging from socioeconomic aspects (such as social inequality [e.g., Lourandos 1997] and prestige competition, [e.g., Hayden 1998]) to environmental or climatic changes (Binford 1983), and population increases (e.g., Cohen 1977). Regardless, we note a positive relationship between the appearance of pottery and the reduction in mobility. The acquisition and transport of bulky raw materials, processing, molding, firing, and/or shaping of pots inhibit human mobility, as does the bulkiness, weight, and fragility of completed vessels. Stone containers are larger, more durable site furniture than ceramic vessels and are also used in intensive processing of starchy wild foods. Stone containers have been discovered in the Zhuannian PNT site (Yu 1998) as well as early Neolithic sites such as Baiyinchanghan (Xinglongwa culture; Neimenggu 2004). These artifacts require substantial effort to manufacture, even with soft stone such as steatite (as at Zhuannian), and unlike ceramics, they did not persist in material culture.

To a forager, mobility is a form of insurance in habitats where resources are distributed variably in time and space (Binford 1983, 2001). Thus, when landscapes become packed and mobility is curtailed, foragers experience high opportunity costs for needed resources and information (Kelly 2013; Winterhalder and Goland1997). Hedging tactics to delay sedentary food production include expansion of diet breadth and intensification of wild resources (e.g., increasing yield per unit area). Interestingly, Chinese PNT pottery does precede agriculture in some cases. This resembles other global sequences: pottery first appeared in Japan as early as 16,000 BP during the Jomon period (Aikens 1995), and in the Russian Far East and Northeast China some ceramics antedate 10,000 BP (Keally et al. 2003, 2004; Kuzmin 2006). Some Mesolithic Europeans and some Native American foragers also made and used pottery. Intensified use of resources and tethered or redundant mobility are in fact compatible with bulky, fragile vessels; thus the emergence of pottery and stone containers during the Chinese PNT heralds important changes in mobility and settlement patterns.

On the other side of the equation, the benefits of pottery include enhanced storage and processing capabilities. The earliest PNT pottery of China may have been used for plant-processing such as cooking seeds (e.g., wild rice, millet, and nut fruits), although this is as yet unproven (Liu 2008). Other foods, such as acorns, require filtering or precipitating of undesirable ingredients. Compared with cooking containers used by mobile foragers (e.g., animal stomachs and skins), pottery has a longer use-life, and unlike stone boiling pits and ovens, pottery can be curated. Thus we propose that in terms of its use in intensified plant processing, pottery is generally not replaceable.

In the middle and lower Yangtze Valley and the neighboring Lingnan region, pottery is a highly visible and common indicator of the PNT—particularly as other PNT traits may be difficult to detect archaeologically. Firing temperatures are quite low for the pottery of these regions. For example, the firing temperature of sherds from the Zengpiyan site is less than 250° C (IA-CASS et al. 2003), similar to that of the loose and fragile sherds found at the Yuchanyan site, about 400 km south of the Yangtze (Yuan 2000, 2013). In contrast, firing temperatures of Shangshan pottery are between 750° and 850° C and likely required a kiln or other firing facility. This supports the current argument that the Shangshan culture most likely represents the early Neolithic stage (Chen and Yu 2017; Sheng et al. 2006) rather than the PNT.

### *Grinding Technology*

Another line of evidence for PNT intensification of wild plant use comes from processing tools such as mortars and pestles. Breaking down hard seed coats requires investment in labor to manufacture these large stone tools and the actual grinding into granules for further processing. We would not expect hunter-gatherers to undertake high-cost processing unless they were under subsistence pressure; thus, stone mortars and pestles are indicative of increasing diet breadth that includes new food species. PNT grinding tools have been discovered in North China sites such as Donghulin (Xie et al. 2006), Nanzhuangtou, Zhuannian, Bianbiandong (Sun et al. 2007, 2014), Kengnan (Song et al. 2011), and Lijiagou (no pestles mentioned), and at Xiachuan (Wang et al. 1978) and Shizitan Locality 9 (Shizitan 2002, 2010) and Longwangchan (Shaanxi 2007; Zhang et al. 2011). Starch residues were extracted from a very early mortar found at the Shizitan site which has been dated to ca. 20,000 uncal BP (Liu et al. 2013; Shizitan 2011). If this date is reliable, plant intensification probably began during the LUP—as early as the oldest pottery from the Yangtze Valley and the Lingnan region. Additionally, disc-like mortars found in Xiachuan (Fuyihe Geliang) exhibit intriguing rounded pits on the working surface (Wang et al. 1978), possibly indicating rotary grinding. This wear type is distinctive of Neolithic mortars and is likely associated with processing pigment or nut fruits.

### *Woodworking Technology*

Partly polished axes with forms similar to later Neolithic blanks have been found in Zhuannian, Xueguan, and Mengjiaquan sites and were likely used for chopping, trimming, and splitting wood. Adzes, used for smoothing and shaping wood, have been found in Donghulin (Cui 2010) and in the Nihewan Basin sites of Yujiagou (Mei

Table 2. Presence of markers of the Chinese PNT, by site

| | | North China | | | | | | | | | | | | | | | South China | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Nanzhuangtou | Zhuannian | Donghulin | Lijiagou | Bianbiandong | Kengnan | Yujiagou | Ma'anshan | Hutouliang | Mengjiaquan | Jijitan | Xuguan | Shizitan† | Xiachuan | Longwangchan | Yuchanyan† | Huadang | Songjiagang | Zhuma | Xianrendong† | Shenxiandong | Zengpiyan | Miaoyan | Dayan |
| Artifact assemblage | Pottery | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ? | | | | | | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Mortars | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | | ✓ | | ✓ | | | | | | | | | |
| | Pestle | ✓ | ✓ | ✓ | | ✓ | | | | | | | | ✓ | | ✓ | | | | | | | | | |
| | Adzes | | | | ✓ | | | ✓ | ✓ | ✓ | | ✓ | | | ✓ | | | | | | | | ✓ | | |
| | Stone container | | ✓ | | | | | | | | | | | | | | | | | | | | ✓ | | |
| | Polished tools | | ✓ | ✓ | ✓ | | | | | | ✓ | | ? | | | ✓ | | | | | | | | | |
| | Diversity of types | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | | | ✓ | ✓ | ✓ | | ✓ | ✓ | | | | ✓ | | |

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site organization | Hearths | ✓ | | ✓ | ? | ✓ | | | ✓ | | | | | | | ? | | | | | | | ? | | |
| | Diversity of types | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | | | | | | | ✓ | | | | | | | ✓ | | |
| | Structures | ? | | ? | ? | ? | | | | | | | | | | | | | | ✓ | | | | | |
| | Graves | | | ✓ | | ? | | | | | | | | | | | | | | | | | ✓ | | |
| | Central camp | ✓ | | ✓ | ✓ | ✓ | | | ✓ | | | | | | | | | | | | | | ? | | |
| | Ditches | ✓ | | ✓ | | | | | | | | | | | | | | | | | | | | | |
| | Pits | ✓ | | | | ✓ | | | | | | | | | | | | | | | | | | | |
| Biological remains | Foxtail millet | | | ? | | | | | | | | | | | | | | | | | | | | | |
| | Broomcorn millet | | | ? | | | | | | | | | | | | | | | | | | | | | |
| | Rice | | | | | | | | | | | | | | | | ✓ | | | ✓ | ✓ | | | | |
| | Dogs | ✓ | | | | | | | | | | | | | | | | | | | | | ? | | |
| | (wild) pigs | ✓ | | | | | | | | | | | | | | | | | | | | ✓ | ✓ | ✓ | |
| | (wild) chickens | | | | | | | | | | | | | | | | | | | | | | ✓ | | |

✓ = present; ?= possibly present

†Shizitan refers to Locality Nos. 9 and 29; Yuchanyan also includes Sanjiaoyan, and Xianrendong also includes Diaotonghuan

2007), Ma'anshan (Xie et a. 2006), Hutouliang, and Jijitan, as well as Xiachuan (Fuyihe Geliang) and Zengpiyan in Guangxi. Microwear analysis on Hutouliang adzes suggests woodworking (X. L. Zhang et al. 2010). In addition to building residential structures, adzes were used to produce handles for composite agricultural tools such as the perforated wooden handle found at Nanzhuangtou (Baoding et al. 1992). Polished spades have been unearthed in Longwangchan (IA-CASS and Shaanxi PIA 2007), and an elongated hoe-like stone tool and a bone spade with a highly polished and worn edge were found at Yuchanyan (Yuan 2013). These tools require extensive labor to produce, have long use-lives, and indicate heavy woodworking and fieldwork that signal reduction in mobility.

## *Lithic Technology*

Although the appearance of artifacts such as pottery and durable stone tools signifies new lifeways at PNT sites, the significance of chipped stone materials has been underestimated. PNT sites without pottery are generally classified as Upper Paleolithic, yet in actuality chipped stone materials dominate almost all lithic assemblages of the PNT. Often regarded as irrelevant remains of outdated technologies, chipped stone lithics manifest the changing mobility of ancient groups and provide complementary information about adaptive changes. Although lithic assemblage characteristics are significantly influenced by accessibility of raw materials, intersite archaeological comparisons should control for this factor. Unfortunately, chipped stone materials are rarely reported in detail in archaeological site reports; we have only been able to extract limited data. Table 3 summarizes assumptions and expected characteristics of core, retouch, debitage, raw material, and tool type ratios we use to infer mobility characteristics from chipped stone materials.

All else being equal, the toolkits of mobile foragers should differ from those of semisedentary agriculturalists. Foragers expect to encounter higher spatial and temporal variability in resource availability, so their toolkits are likely to be flexible and portable. Multipurpose tools such as bifaces and microblade artifacts are produced with standardized retouch that calls for high-quality raw materials. In contrast, early agriculturalists need durable tools for heavy work. At the same time, they may employ small, expedient tools manufactured from local materials since (*a*) the need for high-quality, flexible tools is not as great and (*b*) direct access to high-quality raw materials decreases with reduction in mobility and territorial range. There is less need to prepare cores or tools, and debitage from lithic tool reduction can be reused. Overall, loss of mobility largely lowers the value of multipurpose lithic technologies and increases the usefulness of large, durable tools and expedient chipped stone tools. Contrasts in mobility between foragers and agriculturalists permit us to predict PNT tool assemblage characteristics, even where organic evidence for the earliest agriculture is lacking.

## *Inferences from PNT Artifact Assemblages*

Here we describe adaptive trends of the Chinese PNT by comparing archaeological data with expectations derived from certain assumptions of lithic analyses. Locality 9

Table 3. Influence of reduced mobility on lithic assemblage characteristics

| | Cores | Retouch | Debitage | Raw material | Tools |
|---|---|---|---|---|---|
| Assumptions | Increased sedentism correlated with more informal tools made from expedient cores, whereas mobile foraging requires more formal, curated tools. | Less-mobile foragers invest less time in tool retouch, have less need to be prepared for varied conditions. In general, edge retouch needs less mfr. time than faceted retouch. | Fewer biface thinning flakes indicates less production of formal tools, and expedient (as opposed to prepared) flaking platform reflects less time invested in tool production. | Longer residential time should increase variation in raw materials. Lengthy residence more likely with local, lower-quality raw materials and preforms. Extremely large specimens are most likely from local resources. | Less-mobile groups use expedient tools and heavy, durable tools. Higher mobility calls for standardized formal tools. |
| Measurement | Ratio of standardized artifacts to cores (excluding microcores) | Ratio of faceted retouch to edge retouch | Frequency of biface thinning flakes; proportion of platform retouching flakes to other flakes | Ratio of local to exotic raw materials; diversity of raw materials; presence of extremely large specimens | Ratio of expedient to formal tools: frequency of heavy site furniture/durable tools |
| Expectations | Decreased ratio of standardized artifacts to cores; reduced overall frequency of standardized products | Decreased ratio of faceted to edge retouch: e.g., cruder retouch | Decreased ratio and lower frequency of biface thinning flakes and platform retouching flakes | More local raw materials, diverse types, but less fine raw materials; presence of extremely large specimens; more flakes with cortex | Presence of durable tools; increased ratio of expedient to formal tools |

of the Shizitan site and the Lijiagou site are located in western and eastern sectors of the Taihang Mountains, respectively. Both sites were excavated in recent years and are well-reported. Importantly, their occupational sequences include a PNT stage, which offers a rare opportunity for inter- and intra-assemblage comparisons. The Lijiagou site has three cultural layers (Beijing 2011; Wang et al. 2015; Zhenzhou 2011). The upper stratum is assigned to the early Neolithic Peiligang culture. The middle layer is characterized by a distinctive lithic assemblage of sidescrapers and various choppers, as well as mortar fragments. Most lithics in this layer are expedient tools made from quartz and quartzitic sandstone, with very little chert (by comparison, tools from Lijiagou's lower layer are manufactured from fine raw materials, such as exotic chert). Microblades and microblade cores (wide-platform) are rare in the Lijiagou middle layer compared with the earliest occupation. The pattern of decreased exotic, high-quality raw materials and standardized artifacts, increased expedient tools, and higher variability in artifact form in the middle layer strongly indicates decreasing mobility during the middle occupation.

We can also use this approach for the Shizitan Locality 9 assemblage (Shizitan 2010). This site contains four cultural layers (Layers 1 and 3 assemblages are too small to compare). Layers 4 and 5 yielded 1,119 and 439 lithic artifacts, respectively. According to the above assumptions, less mobile groups would produce more tools at residential sites, in contrast with the preference for mobile people to carry preforms or finished tools. Thus we expect that the proportion of cores relative to products from later in the reduction sequence should be lower in residential sites of less mobile groups, since most products of reduction are used and discarded on-site. In Shizitan's Layer 4, the proportion of cores to end products (flakes, microblades, debitage, and utilized flakes) is 0.032, and it is even lower in Layer 5 at 0.024. If we assume that small debitage results from marginal retouch, and flakes plus broken specimens result from invasive retouch, the ratios (flake total divided by debris total) of Layer 4 and 5 are 2.64 and 1.74, respectively, indicating more invasive retouch in Layer 4. This is consistent with the proportion of cores to end products. Thus mobility during the deposition of Layer 4 at Shizitan Locality 9 was actually *higher* than in the earlier stage (Layer 5), contrary to what we see at Lijiagou.

This could be explained by a chronological difference between Lijiagou and Shizitan (e.g., with Shizitan earlier than Lijiagou), but available radiocarbon dates do not fully support this argument. The hearth in Layer 3 of Shizitan dates to only ca. 8,300 uncal BP (dates are unreported for Layers 4 and 5). Another possibility is regional differences in habitat that influence mobility: the western side of the Taihang Mountains, where Shizitan is located, is more arid than at Lijiagou. This explanation is supported by the lack of early Neolithic materials from Shanxi Province (as described in Barton et al. 2009; Chen and Yu 2017). This scarcity is not attributable to inadequacy of fieldwork, taphonomic processes, or other factors. We suggest that the contrast between Lijiagou and Shizitan indicates that PNT foragers in the western Taihang Mountains retained their mobility longer because of arid conditions that did not favor cultivation, thus delaying the early Neolithic in that region.

## PNT SITE ORGANIZATION

As discussed above, decreased mobility is not necessarily the same as sedentism: shrinkage of foraging territory, less frequent moves, and redundancy of site occupations are "way stations" to full sedentism. With longer and more frequent site occupations, residential sites would become larger, and internally differentiated. In patchy environments, residential sites would be associated with task group camps in a logistical pattern (sensu Binford 1980). Well-sited residential camps would eventually transition to sedentary villages (year-round occupation for multiple years).

Archaeologically, we expect this process to manifest first as a multicomponent site reflecting tethered mobility, with redundant assemblages and features. Next, centralized base camps would contain diverse features and artifact assemblages from varied activities reflecting long-term residence. Features might include structures, storage pits, and substantial hearths; artifact assemblages would reflect reduced mobility as described above. Frequent reoccupations would allow foragers to leave site furniture (e.g., durable artifacts and facilities) for later reuse.

We can now examine PNT site organization to assess expectations for changes in the mobility of pre-Neolithic hunter-gatherers. The Lijiagou site has two layers of living floors that are suitable for comparison. The central part of the earlier living floor contains a stone circle about 3.5 m (east to west) by 2.5 m (south to north). Faunal remains are scattered along its eastern side, mostly long-bone fragments and antlers of large herbivores. In the middle layer, the central part of the site has an accumulation of stones measuring about 3 m long and 2 m wide. This area includes mortars, anvils, and flat stones mixed with fire-cracked rocks, sherds, and bone fragments. The flat stones are mostly local sandstone. These slabs, whose function is yet to be determined, were intentionally transported to the site along with mortars, polished adzes, and sherds. Assuming that investment in site structure would be proportional to the duration of occupation, this indicates that the middle layer at Lijiagou was a centralized base camp of logistically organized, less mobile foragers.

The Shizitan site (Locality 9) appears to represent an early stage of reduced mobility comparable to the lower layer of Lijiagou: a desirable, redundantly occupied area that is part of a mobile foraging round. Shizitan consists of several localities: in Locality 29 (Anonymous 2011), eight cultural layers contain a total of 232 hearths that are similar in spatial organization and artifact assemblages. The dense distribution suggests repeated occupations.

In contrast, a later-stage, centralized residential base camp transitional to semisedentism is exemplified by the PNT sites of Nanzhuangtou and Donghulin. Both sites contain varied artifacts and diverse, abundant features. Nanzhuangtou has ditches, hearths, and storage pits, including one that yielded three antlers with vertical cut marks. A grooved board fragment (ca. 9875 ± 160 cal. BP) may indicate the remains of a structure. The Donghulin site (Figure 2) has ten hearths, one of which (HD3) is about 30 cm in thickness, resembling a typically Neolithic hearth rather than the thinner hearths characteristic of the LUP and the Shizitan site.

The Donghulin site is dated to 13,080 ± 120 BP on charcoal from a large hearth (Xie et al. 2006). A large concentration of black ash contains numerous burned gravels and animal bones, mostly deer. The upper part of this feature is covered by mixed gravels, whereas the lower part is characterized by circularly aligned gravels (Xie et al. 2006; Zhao et al. 2003). Donghulin also has intact graves with multiple burial modes (flexed and extended; primary and secondary) and grave goods of small polished axes and ornaments of bone and snail shell. These features are characteristic of Neolithic era sites, quite different from the fragmented site organization usually found in Paleolithic sites.

With regard to habitats, the geographic locations of resources used by Paleolithic hunter-gatherers are expected to differ from those of Neolithic farmers. Foragers move themselves both to intercept moving resources (prey) and to acquire immovable but often patchy resources such as wild plants, water, and fuel. They occupy caves and other natural features that do not require much construction investment. By contrast, farmers must live close to their fields and construct villages for long-term residence of sizeable populations. PNT site organization shows interesting transitional characteris-

Figure 2. Donghulin site, showing environmental setting.

tics: permanent features and durable tools are similar to the Neolithic, but the geographic locations are still Paleolithic, with many located in caves (e.g., Bianbiandong, Yuchanyan, Xianrendong, Diaotonghuan, and other sites in the Lingnan region). The geographic distribution of open-air PNT sites is also quite different from that of Neolithic sites. As summarized by the excavators at the Xiachuan site (translated here), "we have worked in Xiachuan for several years, but we never found any polished tools and sherds of Neolithic and later periods whether on the surface or in the strata. However, more than 10 km down the main stream of Qinhe River, Neolithic remains were found; yet not any trace of Xiachuan culture. Hence, it seems that Neolithic people never settled in the region of Xiachuan" (Wang et al. 1978:284).

Compared with sites from the preceding Upper Paleolithic, PNT sites are often located adjacent to hilly flanks, such as Donghulin and Zhuannian. Some PNT sites are located in the piedmont zone, such as Nanzhuangtou. In the middle Yangtze Valley, the remains of a high-platform building have been discovered at the Zhuma site (Chu 1999; Yuan 2013). Though the data are limited, these traits reflect a trend toward a typical Neolithic settlement pattern and imply changes in utilization of resources. The shift in PNT settlement toward the floodplain reinforces the gradual nature of the transition, in contrast to the rapid onset of the early Neolithic (Chen and Yu 2017).

With this in mind, we propose the division of PNT settlement into four evolutionary phases. The first is characterized by a logistical collector strategy indicated by relatively stable residential camps sited in productive habitats and reoccupied frequently. In the second phase, tethered use of a given region gradually transitions to exclusively held territories; for example, the Shizitan site. Third, centralized long-term base camps with some Neolithic traits appear in areas downslope from preferred foraging habitats; this phase is exemplified by Donghulin, Nanzhuangtou, Lijiagou, and several other PNT sites with ample remains, diverse lithic assemblages, and typical Neolithic traits (pottery, polished tools, etc.). Recent excavations at the Dadiwan site (Barton et al. 2009) are representative of the first three phases. Finally, the fourth phase consists of characteristic sedentary Neolithic villages established on the floodplains of North China and the middle and lower Yangtze Valley.

## SUBSISTENCE AND RESOURCE USE

### *Faunal Remains at PNT Sites*

Faunal remains are generally scarce and highly fragmented in North China PNT sites. This is not due exclusively to natural processes, as abundant bone fossils have been found from such LUP sites as Shiyu (Jia et al. 1972), Zhoukoudian Upper Cave (Pei 1939), and Xiaonanhai (An 1965). The high degree of fragmentation may relate to intensified processing of increasingly scarce animal prey in the PNT (although see Lupo et al. 2013). This coincides with vegetation changes: floral data from Donghulin show 55% woody plants including thermophilic pine, spruce, oak, walnut, and even hemlock (now present only in subtropical zones). Overall, early Holocene herbaceous cover decreased in this region after the late Pleistocene because of the expansion of forests in some areas (Xia et al. 2011). The loss of grazing habitats may explain the decrease in large ungulates near Donghulin.

This trend is observable in the lower PNT layer of the Lijiagou site. Large-body-size animals dominate the assemblage from the lower layer, while the middle layer is dominated by small animals with only a few bones from caprids, pigs, and small carnivores. Similarly, Locality 9 of the Shizitan site yielded 695 bone fragments mostly 1 to 2 cm long, with more than 70% being burned and highly fragmented. Animals identified using features of teeth and joints include rodents, rabbits, carnivores, antelope, and birds (including ostrich). Thus both the Shizitan and Lijiagou faunal assemblages indicate notable decreases in large herbivores accompanied by expansion of hunting diet breadth to include smaller prey.

An exception is the modern deer (*Cervus nippon* spp.), which indicates higher resiliency to early Holocene pressures than bovids, horses, and pigs. Deer were apparently the favored prey of North China PNT hunters, as this species predominates in faunal remains at Nanzhuangtou (Yuan and Li 2010), Xianrendong (Redding 1995), and Donghulin (Liu et al. 2010; Xie et al. 2006). Deer were also favored by Neolithic "farmers" of the Yangtze Valley. Deer generally live at forest-grassland ecotones, so the expansion of forest habitats after the last glacial period may have expanded suitable habitats.

The pattern of high-diversity faunal assemblages is evident at the early pottery sites of Yuchanyan and the Lingnan region. The Yuchanyan faunal assemblage clearly displays a preference for freshwater aquatic resources, and the Zengpiyan site's abundant collection of animal remains includes a rich assemblage of aquatic species (IA-CASS et al. 2003), indicating that PNT diet breadth expanded to include aquatic prey. Mixed aquatic-terrestrial faunal assemblages have been discovered at Miaoyan (Zhang et al. 1999), Bailiandong, Liyuzui, Huangyandong (Guangdong), and other Lingnan caves occupied at about the same time.

During the PNT, an aquatic subsistence specialization became a characteristic adaptation of the Lingnan region that persisted throughout the entire Neolithic sequence. The Lingnan sites' distance from and elevation above natural streambeds indicate that aquatic remains are almost certainly culturally deposited. In contrast, shellfish are rarely found in the PNT sites of the middle and lower Yangtze Valley. Thus we infer that the extent of dependence on aquatic resources separates the Lingnan region from the middle and lower Yangtze Valley. Shellfish are a protein source that can be gathered by people of most ages and physical ability, unlike hunting and fishing, which require strength, skill, and complicated toolkits. Shellfish can offset shortages of hunted resources, alleviating subsistence pressure that would otherwise be a precondition for animal domestication. Aquatic resource procurement in the PNT reflects both a novel adaptation and a resource intensification strategy.

Concurrent with decreased big-game hunting and increased utilization of aquatic resources, evidence for animal domestication increased during the PNT stage. A mandible found at the Nanzhuangtou site is regarded as being from a domesticated dog (Yuan and Li 2010), although canine domestication had already occurred by the LUP. Specimens of possibly domesticated canids are also found in Xianrendong. For pigs, the features of domestication are somewhat ambiguous; pig remains found at Nanzhuangtou do not exhibit clear anatomical evidence (Yuan and Li 2010). Age profiles of pig remains unearthed at the Zengpiyan site are similar to those of wild boars (IA-CASS et al. 2003). Thus with the exception of dogs, the domestication of animals (pigs, chickens, cattle, and/or buffalo) occurred after plant domestication. Animals were fed stalks, husks, and other by-products from human processing and consumption of crops. The large proportion of wild animal bones in early Neolithic assemblages indicates that hunting remained an important means of procuring meat and fur. We expect that animal domestication accompanied by sedentism was not well-established until the middle Neolithic.

### *Botanical Remains at PNT Sites*

Plant remains are well-represented at Cishan (Crawford 2009), Donghulin (Liu et al. 2010), Shizitan (locality 9) (Liu et al. 2011), Yuchanyan (e.g., Yuan 2013), and Zengpiyan (IA-CASS et al. 2003). Recent analyses indicate that domestication of millet began in North China around 10,000 years ago (Crawford 2009; Lu et al. 2009; Shen et al. 2009; Yang et al. 2012). Barton et al. (2009) document heavy dependence on millet at the Dadiwan site, evidenced by isotopic analysis of dog skeletons, by the late Neolithic (ca. ~7,500 uncal BP). Wild plant intensification is indicated by hundreds of hackberry seeds (*Celtis* spp.) found in Grave No. 4 of the Donghulin site. Hao et al. (2008) argue that mortars found in Donghulin were probably used to process hackberries in a way similar to that of Native Americans, who ate the flesh and pulverized the seeds for later consumption. Liu et al. (2010) also found acorn starch residue on Donghulin grinding stones.

In the south, diverse macrobotanical remains from Yuchanyan cultural deposits include at least 40 species in an assemblage that is dominated by hackberry seeds (Yuan 2013). Eleven rice grains with features intermediate between wild and domesticated varieties have been found (Zhang and Yuan 1998). The origins of rice domestication have been explored through phytolith analysis at Xianrendong and Diaotonghuan (Zhao 1998, 2000; Zhao et al. 1995). As Zhao (1998, 2000) reports, 14 soil samples were collected from the upper to lower layers (Layers A to G) at Diaotonghuan. Phytoliths were particularly abundant in Layer G (ca. 17,040 ± 270 cal BP); these phytoliths still indicate wild rice, whereas Layer C is mostly domesticated rice, and the rice in Layers E and D (ca. 11,900 cal BP) is transitional. The absence of rice phytoliths in Layer F (ca. 15,180 ± 90 cal BP) remains to be explained. Given the possible contamination of the radiocarbon dates (clay, a carrier of carbon, is common in South China sites; Boaretto et al. 2009), Layer F may have been deposited later, during the Younger Dryas (13,900~12,800 BP), when cooling climates would not favor wild rice at this latitude.

The conclusions drawn from rice remains are in fundamental agreement at sites such as Yuchanyan and Diaotonghuan: domesticated rice appeared at about 12,000 BP when the climate warmed sufficiently in zones that had previously been marginal for rice growth. Although these conditions may still have been relatively cool for rice cultivation, in some cases this can help increase rice grain productivity. For instance, observation under modern climatic conditions suggests that wild rice of the Yangtze Valley on average has more seeds than that of the warmer Lingnan region (Chen 1990; Lu 2013). Of course, wild rice was very likely harvested by foragers long before the PNT.

In the Lingnan region, substantial plant remains have been recovered at Zengpiyan under a systematic flotation program. Comparison of the total weight of carbonized materials, tubers, and numbers of plant seeds suggests a significant change between Zengpiyan cultural phases III and V. The frequency of tuber remains increases through time, but no rice remains, either domesticated or wild, have been found even with phytolith analysis. Thus it is highly unlikely that people at Zengpiyan practiced rice agriculture (IA-CASS et al. 2003). Overall, the early Neolithic in the Lingnan region shows a different view of subsistence than the domesticated rice later developed at Yuchanyan, Xianrendong, and Diaotonghuan. People at Zengpiyan instead depended on aquatic resources and tubers, mixed with some seed crop cultivation. This mode of farming, termed low-level food production or vegeculture by Smith (2001), is interesting in its own right. Tubers and other protodomesticated species allow expansion of diet breadth and reduced risk, while enabling people to maintain some mobility. Tubers thrive under variable soil and water conditions, can be propagated by planting stems (rather than seeds), are resistant to pests and diseases, and self-store underground. Thus the Zengpiyan macrobotanical evidence suggests an interesting cultivation strategy that allows for some mobility to persist, echoed later in Neolithic Taiwan, the Philippines, and parts of Oceania (Bellwood 2007).

## WHAT DO THESE CHANGES MEAN? THE INTENSIFIED FORAGING ROOTS OF AGRICULTURE

The initial conditions for agriculture lie in intensified foraging, and the PNT of North China and the Yangtze Basin offers a very interesting view of human-ecosystem relationships during the time of agricultural origins. Prior to the PNT, Chinese archaeological data indicate a strategy of foraging intensification through multiple strategies: the first was alteration of foraging mobility toward repeated occupation of favored regions. Frequent reuse of an area would hasten the depletion of local wild resources beyond the natural replacement rate. This is clearly shown in the North China site complexes of Shizitan, Xiachuan, and Nihewan.

The second strategy was a shift to broad-spectrum utilization of animal resources: PNT faunal assemblages of North China show a clear decrease in large herbivores relative to the preceding LUP. The intensity of bone processing increases, as reflected by the high degree of fragmentation. In the Yangtze Valley and the Lingnan region, the addition of birds, reptiles, and amphibians to the PNT diet further indicates dramatic expansion of foraging diet breadth down the body size gradient.

A third intensification strategy was a new focus on the aquatic biome to acquire protein through intensified shellfish gathering and the use of enhanced technology to procure fish and other swimming species. In PNT sites, evidence of utilization of aquatic resources is widely found in the Lingnan region, and sporadically in the middle and lower Yangtze Valley.

The fourth intensification tactic is adding wild plant foods that require labor and specialized technology to make them digestible for humans. According to Binford's (2001) synthetic study of more than 400 hunter-gatherer groups, this type of plant intensification is used in landlocked settings where hunting-dependent subsistence cannot be sustained, and aquatic resources are not available.

Overall, changes in subsistence, mobility, and settlement in the archaeological record reflect density-dependent tactics of innovation and experimentation—tactics that varied in tempo and mode according to opportunities and constraints of the local environment. Summary data on paleodiets of the early Neolithic (Chen and Yu 2017) indicate that early domesticated foods were of minor importance in diverse ecosystems that offered aquatic and vegeculture options. A prolonged stage of low-intensity mixed foraging and farming would have preceded the cessation of foraging and intensive agriculture (also see Johnson 1997; Yu 2009). In resource-poor habitats where intensification of wild plant use was a necessity, the transition to agriculture is expected to proceed more rapidly.

### *Divergent Evolutionary Pathways*

This premise can be assessed in our two major study regions. By the Upper Paleolithic, increasing territoriality as a density-dependent response to population growth had given rise to diversified social organization indicated by regionalization of lithic assemblages. North China shows a distinctly different route than the middle and lower Yangtze Valley. In general, the Neolithic appeared in both areas almost simultaneously, but the archaeology of the western part of North China and the Lingnan indicates distinct regional pathways.

Based on recent archaeological discoveries in North China, we propose four Early Upper Paleolithic (EUP) regional patterns: Shuidonggou, Shiyu, Upper Cave–Wangfujing, and Xiaogushan (Chen 2006). At the Last Glacial Maximum, these variable lithic assemblages became dominated and overprinted by microblade technology. This specialized lithic system developed first through integration and standardization, followed by wide dispersal throughout North Asia and eventually as far as North America (see Lee 2007 for summary).

Subsistence in the ensuing PNT exhibits a similar sequence: initiation of agriculture in suitable North China habitats, persistence of intensified foraging elsewhere, and eventual expansion and predominance of agriculture. First, differentiation in UP foraging intensification is evident at the Shizitan and Lijiagou sites with a clear cultural differentiation between eastern and western regions of the Taihang Mountains. In the Loess Plateau, Neolithic traits arrived much later than in the east—in the west it arrived only in the middle Neolithic. Farther west in the grasslands, microblade technology continued to predominate into the Neolithic and as late as the historical period. The second stage is the development of the early Neolithic in the hilly flank zones and floodplains of North China. Agriculture appears early in the eastern Taihang region, and a cultural variant in the northern area beyond the Yan Mountains (sometimes called the Liaoxi region) shows no PNT evidence but rather a well-developed Neolithic cultural sequence. Early Neolithic sites such as Xinglongwa and Xiaohexi represent a distinctively mixed economy.

As in the early Neolithic, habitat opportunities and constraints played a major role in the diversity of the North Chinese PNT (Chen and Yu 2017). A hallmark of agricultural origins is the formation of a new niche with different cultural-ecological relationships: sedentary living restricted to the floodplains undoubtedly would have been viewed unfavorably by hunter-gatherers, who need mobility to access wild resources and vital information about local conditions (also see Binford 1983; Kelly 2013; Yu 2015). Thus the geographic differences in optimal habitats for foraging versus farming, and the resulting constraints on mobility, were more evolutionarily significant than the domestication of plants and animals per se. Foraging persisted where favored, but eventually even optimal habitats for hunter-gatherers (e.g., wide valleys, basin margins, hilly flanks) became colonized by sedentary agriculturalists radiating outward and upward from their early homes on the floodplains. The PNT of North China shows that the piedmont zone between the mountains and floodplains offered late-stage foragers the opportunity to remain mobile and practice mixed subsistence (Figure 3), until supplanted by sedentary agriculturalists.

In the middle and lower Yangtze Valley during the Late Upper Paleolithic, choppers and chopping tools continued to prevail in lithic assemblages of the west, while sites in the east show a tendency toward miniaturization (small flint flake tools). We include the Lingnan region in this discussion, as the PNT stage began almost simultaneously in both southern regions. Climates in southern regions ameliorated to warm-temperate after the LGM, albeit still cooler than Holocene conditions (Huang and Zhang 2000; Huang et al. 2002). At ca. 12,000 BP in the middle and lower Yangtze Valley (i.e., floodplain and terraces), the coniferous forests of the glacial period were succeeded by the temperate conifer forest (Figure 4), while in Lingnan the cool-temperate forest transitioned to subtropical vegetation (Winkler and Wang 1993).

As discussed earlier, this interesting region did not fully develop cereal agriculture as quickly as the Yangtze Valley but instead used a mixed strategy of low-level vegeculture dependent on roots and corms, augmented by aquatic resources in a pattern similar to the Middle Neolithic of Southeast China, Taiwan, and the Philippines (Jiao 2007, 2013). Thus subsistence pressure could be offset by relatively plentiful wild plants and rich aquatic resources. Constraints and opportunities exerted both "push" and

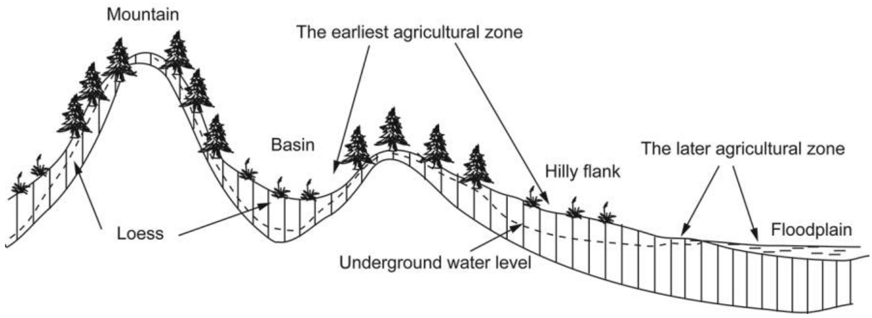


Figure 3. Schematic of Chinese vegetation zones preferred by earliest farmers.

"pull"; cultivation in Lingnan was constrained by environmental conditions, where nutrients are limited in subtropical soils, and seed crops are subject to pests, disease, and competition from abundant wild plants.

Thus, despite their simultaneous and nearly identical initial adaptive responses to LGM climate change, the Lingnan region subsequently took a different pathway from the middle and lower Yangtze Valley. The PNT divergence is apparent when the early onset of rice agriculture in the middle and lower Yangtze Valley (although see Fuller et al. 2008 for an alternative model) is compared with the use of low-level vegeculture/aquatic resources in the Lingnan region. This bifurcation occurred at about 11,000 BP.

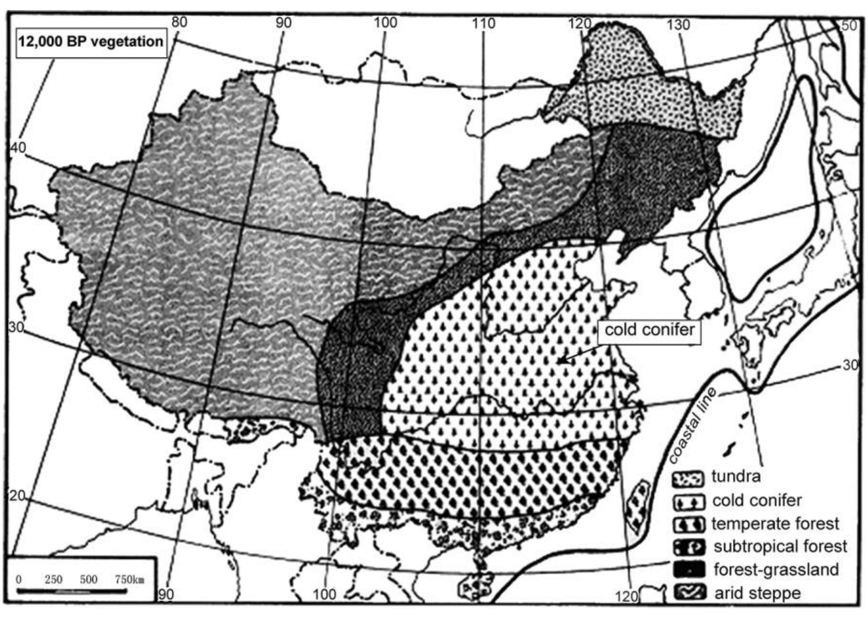


Figure 4. Biogeographic zones of China ca. 12,000 BP (redrawn from Winkler and Wang 1993: fig. 10.11).

With improving rice agriculture technology and the growth of middle to late Neolithic populations, rice agriculture eventually spread to Lingnan in a pattern similar to that shown for western North China.

## CONCLUSION: OF RISK AND REVOLUTIONS

Larger sample sizes and improved chronological resolution of archaeological materials call for the designation of the PNT as a valid cultural stage with clear basic attributes that allow inferences regarding cultural processes. We now know that the PNT transition was more rapid in some regions of China than in others. An evolutionary approach to cultural processes calls for the analysis of historical stressors or drivers (environmental or climate change, population increase, etc.) that played out against a backdrop of varied initial conditions. Behavioral ecological explanations for variance in the rate of agricultural adoption include Bettinger et al.'s (2010) citation of social conventions among foragers that prohibit land ownership and Zeanah's (2004) and Thomas's (2015) descriptions of increasingly logistical modes of subsistence driven by the greater distances between preferred foraging areas and settlements. The common thread seeks to quantify the costs and benefits of food production to discerning groups of hunter-gatherers operating in variable habitats and social contexts. One further step is to assess relative costs of crop types by identifying characteristics that would have influenced forager decision-making.

The evolutionary fork in the road to Chinese agricultural origins arose from underlying conditions such as climatic stability (Richerson et al. 2001), habitat structure and resiliency (Sherrat 1996), and wild species with adaptational characteristics suitable for domestication (Diamond 1997). We agree with Winterhalder and Goland (1997) that the development of agriculture stems from the minimization of foraging subsistence risk, especially in seasons of wild resource scarcity. Risk arises not only from changes in the absolute quantity of resources per consumer but also from unpredictability of resources in time and space. Full-blown agricultural production reduces interannual variability with seed crops that are suitable for relatively long-term storage (seen in the Chinese archaeological record). Therefore we expect that the collection and processing of wild plant seeds will precede the development of seed crop agriculture; this is indeed the case in the PNT of China. The first agriculture may appear "revolutionary," but farming was invented by foragers as an adaptive process that followed tactically, and logically, from intensification of wild plant foods. The tempo and mode of this process can be predicted based on the occurrence of environmental conditions and social complexity that facilitates technological experimentation and transfer.

Two characteristics of the Chinese PNT stand out: first, the germination of material culture traits that later became Neolithic hallmarks, with pottery preceding domestication (the reverse of evidence in the Near East), and second, a divergent path with early agricultural development and a rapid process of sedentization in floodplain regions versus persistence of intensified Paleolithic foraging tactics in others. Within the agricultural sphere, three traditions—rice farming in Yangtze Valley, dryland farming centered in North China, and tropical agriculture in Lingnan (Zhao 2011)—have existed since the PNT. This threefold division is distinctive in the Chinese case and suggestive for research in other areas of the world.

We have developed a conceptual scheme depicting the adaptive "sweet spot" for initial agriculture in landlocked environments of China (Figure 5). In these habitats, hunting and fishing were no longer major contributors to foraging and subsistence had become focused on wild terrestrial plants. When stressors occur, agriculture is expected to appear at the tilting point where mobility opportunity costs to foragers became offset by the benefits of sedentism. Behavioral ecology predicts that once foraging population densities reached a threshold where labor forces could be mobilized and intensified foraging no longer met subsistence needs, sedentary cultivation was not only feasible, but necessary.

Understanding the ways in which environments favor the continuation of hunting and gathering is essential to explaining the regional differences in first farming that we observe in the Chinese archaeological record. Multimodal patterning in PNT sequences indicates that a one-size-fits-all model of agricultural development is no longer defensible. Well-documented variability in cultural innovation proceeds according to the relationship among population density, resource structure, and habitat type: in China, harsh environmental conditions that render initial agriculture too costly (as

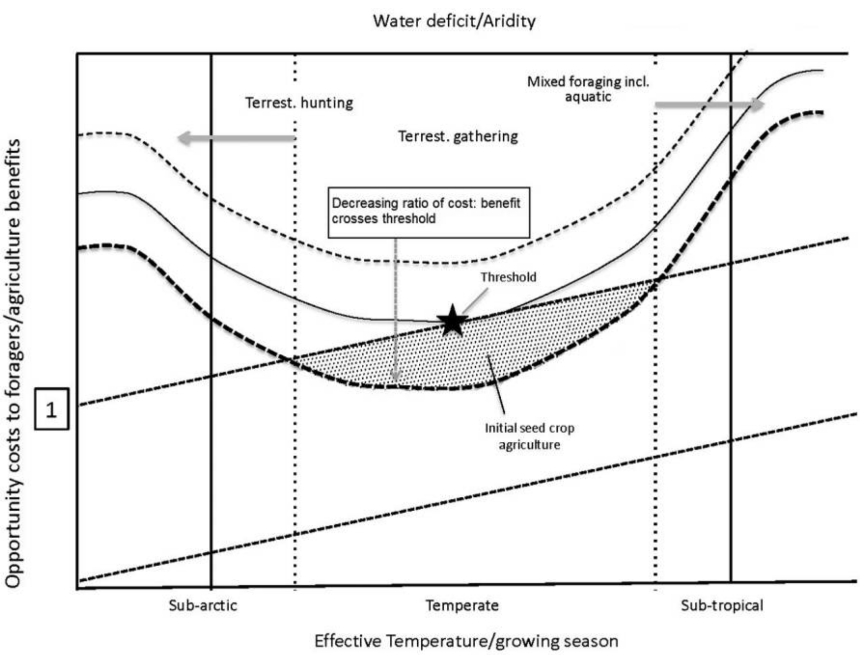


Figure 5. Foraging opportunity costs and environmental zones that favor initial experimentation with agriculture.

in the north) or wet environments that offer alternatives to full investment (as in the south) will delay the onset of intensified seed crop monoculture. The sporadic appearance in China after the LGM of grinding stones and pottery suggests that these technologies paid off during the Pleistocene only under certain conditions (Elston et al. 2011).Only when sedentary farmers refine seed cropping techniques to succeed in a range of habitats, and farming populations "spill over" into foraging territories, do we expect seed-based agriculture to spread to all habitat types. Figure 6 shows the next evolutionary step, in which seed crop farming becomes established and begins to spread into areas where hunting, vegeculture, and aquatic resources had—up to this point—allowed foraging to persist into the Neolithic.

We adopt Binford's (2001) use of thermodynamic terms to call the transition to the Neolithic a *system transformation*, one that took place when stressors overwhelmed the system's damping mechanisms (adaptation) and pushed it across a threshold to a new level of energetic organization. In China, the habitats preferred for foraging versus initial farming may not have overlapped, implying that changes in mobility and sedentism during a transition from foraging could alternately favor mixed foraging and farming, full-fledged farming, or even reversal back to foraging (sensu Winterhalder and Kennett 2006:17). Similarly, Barlow (2002) gives an exemplary explanation of maize agriculture in the American Southwest. A slight change in the ratio of opportunity costs to benefits, especially early in the transition, could cause the agricultural "bulge" in Figure 6 to move back upward. For the diffusion of established

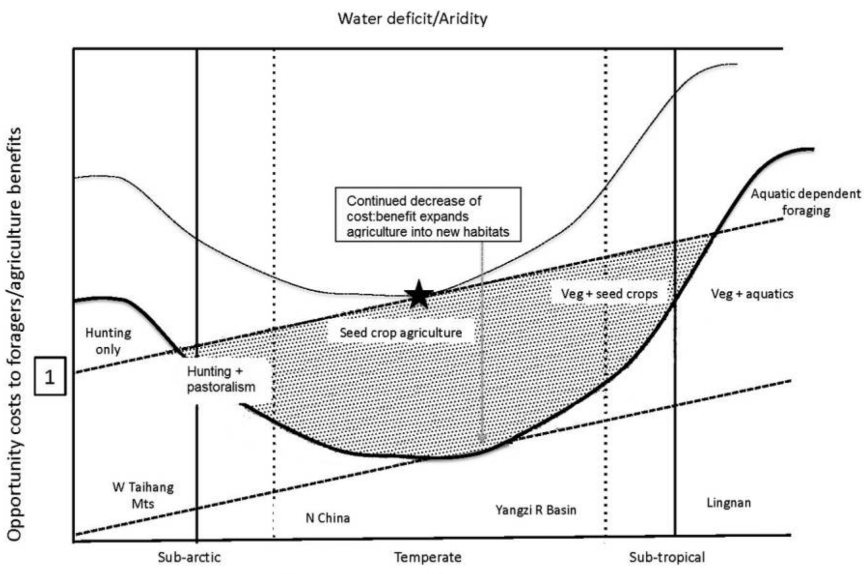


Figure 6. Opportunity costs shift: Expansion of agriculture into environmental zones previously favoring foraging or vegeculture/mixed subsistence with growing population density.

crops into new areas, a promising approach from human behavioral ecology is the ideal free distribution model that seeks to explain how farming took root according to variably favorable properties of new habitats (Kennett et al. 2006).

To conclude, the changes that led to the origins of Chinese agriculture in core regions were gradual and uneven, transpiring over several thousand years and initiated by foragers. Variability in these processes can be predicted according to measurable properties of habitat, resource structure and distribution, and human population dynamics. The seemingly contradictory term "revolutionary transition" is appropriate here and in other areas of the world (e.g., Boyd 2006). Scale is key to discerning these patterns: we may never be able to describe the details of the transition from hunting and gathering to agricultural societies as well as, say, more recently documented transitions from agricultural to industrial societies. Nevertheless, archaeologists have a unique ability to summarize large bodies of data from both cultural and natural perspectives and form testable hypotheses to predict when change will happen, when it will not, and how evolutionary variability may occur—in ways that natural scientists cannot characterize and ancient participants could never imagine (Binford 1989:474). China is an ideal place for this kind of research, which will continue to have implications for other cultural sequences across the globe. Our research is a processual perspective on the PNT question, and increasing the resolution of archaeological records and advances in archaeological method and theory will promote the testing of hypotheses about the internal structure of Upper Paleolithic societies and ensuing social changes during the origin of agriculture.

## NOTES

This research is funded by the Renmin University of China program for faculty from foreign countries, and the Chinese National Fund for Social Science (14BKG021). We are most grateful for Wang Youping, Zhao Chaohong of Peking University, Yuan Jiarong, Yin Jianshun of Hunan Provincial Institute of Archaeology and Cultural Relics, Shi Jinming and Wang Yiren of Shanxi Provincial Institute of Archaeology for helping us observe and understand archaeological records. The authors are also grateful for the insightful suggestions of anonymous reviewers. Finally we owe a great debt to our mentor Lewis R. Binford for his stimulating research in the field of Post-Pleistocene adaptations.

1. Pinyin spelling is used throughout the paper except in direct quotations and references.

## REFERENCES CITED

Aikens, C. M. 1995. "First in the world: The Jomon pottery of early Japan," in *The emergence of pottery: Technology and innovation in ancient societies*. Edited by W. K. Barnett and J. W. Hoopes, pp. 11–21. Washington, DC: Smithsonian Institution Press.

Anonymous. 2011. Shizitan Paleolithic site, Ji County (in Chinese). *Zhongguo Wenwu Bao*, Jan. 7.

An, Z. 1965. Test excavation at Xiaonanhai, a Paleolithic cave site in Anyang, Henan (in Chinese). *Kaogu Xuebao* 1965(1):1–27.

Baoding [Baoding Diqu Wenwu Guanlishi, Xushui Xian Wenwu Guanlisuo, Beijing Daxue Kaogu Xi, Hebei Daxue Lishi Xi]. 1992. The test excavations at the Nanzhuangtou site in Xushui County, Hebei (in Chinese). *Kaogu* 1992(11):961–70.

Barlow, K. R. 2002. Predicting maize agriculture among the Fremont: an economic comparison of farming and foraging in the American Southwest. *American Antiquity* 67:65–88.

Barton, L., S. D. Newsome, F. Chen, H. Wang, T. P. Guilderson, and R. L. Bettinger. 2009. Agricultural origins and the isotopic identity of domestication in northern China. *Proceedings of the National Academy of Sciences (USA)* 106:5523–28.

Beijing [Beijing Daxue Kaogu Wenbo Xueyuan, Jiangxi Sheng Wenwu Kaogu Yanjiusuo]. 2014. *Xianrendong and Diaotonghuan* (in Chinese). Beijing: Wenwu Publishing House.

Beijing [Beijing Daxue Kaogu Wenbo Xueyuan, Zhenzhou Shi Wenwu Kaogu Yanjiuyuan]. 2011. A brief report of excavation in Lijiagou site, Xinmi city, Henan Province (in Chinese). *Kaogu* 2011(4):3–9.

Bellwood, P. 2007. "Southeast China and the prehistory of the Austronesians," in *Lost maritime cultures: China and the Pacific*. Edited by T. L. Jiao, pp. 36–53. Honolulu: Bishop Museum Press.

Bettinger, R. L., L. Barton, and C. Morgan. 2010. The origins of food production in North China: A different kind of agricultural revolution. *Evolutionary Anthropology* 19:9–21.

Bettinger, R. L., L. Barton, P. J. Richerson, R. Boyd, H. Wang, and W. Choi. 2007. "The transition to agriculture in northwestern China," in *Late Quaternary climate change in Quaternary sciences*. Edited by D. B. Madsen, F. Chen, and X. Gao, pp.83–101. Amsterdam: Elsevier.

Binford, L. R. 1980. Willow smoke and dogs' tails: Hunter-gatherer settlement systems and archaeological site formation. *American Antiquity* 45(1):4–20.

———. 1983. *In pursuit of the past*. New York: Thames and Hudson.

———. 1989. *Debating archaeology*. San Diego: Academic Press.

———. 2001.*Constructing frames of reference: An analytical method for archaeological theory building using ethnographic and environmental data sets*. Berkeley: University of California Press.

Boaretto, E., X. Wu, J. Yuan, O. Bar-Yosef, V. Chu, Y. Pan, K. Liu D. Cohen, T. Jiao, S. Li, H. Gu, P. Goldberg, S. Weiner, and B. D. Smith. 2009. Radiocarbon dating of charcoal and bone collagen associated with early pottery at Yuchanyan Cave, Human Province, China. *Proceedings of the National Academy of Sciences (USA)* 106:9595–9600.

Boyd, B. 2006. On "sedentism" in the later Epipalaeolithic (Natufian) Levant. *World Archaeology* 38(2):164–78.

Chen, H. 1990. A brief report on the wild rice of Dongxiang (in Chinese). *Nongye Kaogu* 1990(2): 274–75.

Chen, S. 2006. Environment adaptation and diffusion of North China humans in Late Pleistocene (in Chinese). *Quaternary Sciences* 26:522–33.

———. 2013. The Pleistocene to Holocene adaptive changes of hunter-gatherers in Northeast China. *Asian Archaeology* 1:26–43.

Chen, S., and P. Yu. 2017. Early "Neolithics" of China: Variation and evolutionary implications. *Journal of Anthropological Research* 73(2):149–80.

Chu, Y. 1999. The building structure of the terminated Paleolithic in Zhuma, Li County. *Annual Chinese Archaeology 1997* (in Chinese). Beijing: Cultural Relics Publishing House.

Cohen, M. N. 1977. *The food crisis in prehistory*. New Haven: Yale University Press.

———. 2009. Rethinking the origins of agriculture. *Current Anthropology* 50(5):591–95.

———. 2009. Agricultural origins in North China pushed back to the Pleistocene-Holocene boundary. *Proceedings of the National Academy of Sciences* 106:7271–72.

Cui, T. 2010.*The study of the lithic assemblage from Donghulin site: The lithic industry and human behavior in the transition of Paleolithic and Neolithic* (in Chinese). Ph.D. dissertation, School of Archaeology and Museology, Beijing University, Beijing.

Diamond, J. 1997. *Guns, germs and steel*, New York: Norton.

Elston, R. G., G. Dong, and D. Zhang. 2011. Late Pleistocene intensification technologies in northern China. *Quaternary International* 242:401–5.

Fuller, D., L. Qin, and E. Harvey. 2008. "Evidence for a late onset of agriculture in the Lower Yangtze region and challenges for an archaeobotany of rice," in *Past human migrations in continental East Asia: Matching archaeology, linguistics and genetics*. Edited by A. Sanchez-Mazas, R. Blench, M. Ross, I. Pejros, and M. Lin, pp. 40–83. London: Routledge.

Germonpré, M., M. Láznicková-Galetová, and M. V. Sablin. 2012. Paleolithic dog skulls at the Gravettian Předmostí site, Czech Republic. *Journal of Archaeological Science* 39:184–202.

Gremillion, K. J. 1996. Diffusion and adoption of crops in evolutionary perspective. *Journal of Anthropological Archaeology* 15(2):183–204.

———. 2002. Foraging theory and hypothesis testing in archaeology: An exploration of methodological problems and solutions. *Journal of Anthropological Archaeology* 21(2):142–64.

Gremillion, K. J., and D. R. Piperno. 2009. Human behavioral ecology, phenotypic (developmental) plasticity, and agricultural origins. *Current Anthropology* 50(5):615–19.

Hao, S., Xue, J., and Cui H. 2008. Seeds of *Celtis* L. accompanied with occurrence of "Donghulin Man 4" (in Chinese). *Acta Anthropologica Sinica* 27:249–54.

Hayden, B. 1998. Practical and prestige technologies: the evolution of material systems. *Journal of Archaeological Method and Theory* 5:1–53.

Hebei [Hebei Wenwu Yanjiusuo, Baoding Shi Wenwu Guanlisuo, Xushui Xian Wenwu Guanlisuo, Shanxi Daxue Lishi Wenhua Xueyuan]. 2010. The excavation report of 1997 in Nanzhuangtou site, Xushui County, Hebei Province (in Chinese). *Kaogu Xuebao* 2010 (3):361–85.

Hebei [Hebei Wenwu Yanjiusuo, Tangshan Shi Wenwu Guanlisuo, Yutian Xian Wenwu Baohu Guanlisuo]. 1991. A brief report on the excavation of the Paleolithic Mengjiaquan site, Yutian, Hebei (in Chinese). *Wenwu Chunqiu* 1991(1):1–13.

Huang, Z., and W. Zhang. 2000. The shift of tropical zone during the Last Glacial Maximum in China (in Chinese). *Acta Geographica Sinica* 55:587–95.

Huang, Z., W. Zhang, and Lu Jiang. 2002. Shift of the north boundary of China's tropics during Holocene (in Chinese). *Quaternary Sciences* 22:359–64.

IA-CASS [Zhongguo Shehui Kexueyuan Kaogu Yanjiusuo]. 2010. *Chinese archaeology: Neolithic archaeology* (in Chinese). Beijing: Chinese Social Sciences Press.

IA-CASS [Zhongguo Shehui Kexueyuan Kaogu Yanjiusuo], the Archaeology Team of the Zhuang Autonomous Region, the Zengpiyan Archaeology Museum, and the Archaeology Team of Guilin City. 2003. *Zengpiyan: A prehistoric site in Guilin* (in Chinese). Beijing: Cultural Relics Publishing House.

IA-CASS and Shaanxi PIA (Provincial Institute of Archaeology). 2007. Longwangchan Paleolithic site of Yichuan County, Shaanxi Province (in Chinese). *Kaogu* 2007(7):3–8.

Jia, L., Y. You, and P. Gai. 1972. The report of excavation at Shiyu, a Paleolithic site in Shanxi (in Chinese). *Kaogu Xuebao* 1972(1):39–58.

Jiao, T. 2007. *The Neolithic of Southeast China: Cultural transformation and regional interaction on the coast*. Youngstown, NY: Cambria Press.

———. 2013. "An economic perspective of Southeast China's prehistory—in memory of Professor Kwang-Chih Chang." In *Rethinking East Asian archaeology: Memorial essay collection for the tenth anniversary of Kwang-Chih Chang's death*. Edited by K. T. Chen, pp. 21–36. Taipei: Institute of History and Philology, Academia Sinica.

Jordan, P., and M. Zvelebil, eds. 2009. *Ceramics before farming*. London: Institute of Archaeology, University College of London.

Johnson, A. 1997. *Explaining variability in the pace and pattern of cultural evolution in the Southwestern United States: An exercise in theory building*. Ph.D. dissertation, Southern Methodist University. Ann Arbor: University Microfilms.

Keally, C., Y. Taniguchi, and Y. V. Kuzmin. 2003. Understanding the beginnings of pottery technology in Japan and neighbouring East Asia. *Review of Archaeology* 24:3–14.

Keally, C. T., Y. Taniguchi, Y. V. Kuzmin, and I. Y. Shewkomud. 2004. Chronology of the beginning of pottery manufacture in East Asia. *Radiocarbon* 46:345–51.

Kelly, R. L. 2013. *The lifeways of hunter-gatherers: The foraging spectrum*. Cambridge: Cambridge University Press.

Kennett, K., A. Anderson, and B. Winterhalder. 2006. "The ideal free distribution, food production, and the colonization of Oceania," in *Behavioral ecology and the transition to agriculture*. Edited by D. Kennett and B. Winterhalder, pp. 265–88. Berkeley: University of California Press.

Kramer, K. L., and R. D. Greaves. 2014. Hunter-gatherer use of wild plants and domesticates: Archaeological implications for mixed economies before agricultural intensification. *Journal of Archaeological Science* 41(2014):263–71.

Kuzmin, Y. V. 2006. Chronology of the earliest pottery in East Asia: Progress and pitfalls. *Antiquity* 80:362–71.

Larson, G., E. K. Karlsson, A. Perri, M. T. Webster, S.Y.W. Ho, et al. 2012. Rethinking dog domestication by integrating genetics, archaeology, and biogeography. *Proceedings of the National Academy of Sciences USA* 109, 8878–83.

Lee, C. M. 2007. *Origin and function of early Holocene microblade technology in southeast Alaska, USA*. PhD dissertation, University of Colorado, Boulder.

Linfen [Shanxi Sheng Linfen Xian Wenwuju]. 1989. Mesolithic remains from Shizitan, Ji County, Shanxi Province (in Chinese). *Kaogu Xuebao* 1989(3):305–22.

Liu, L. 2008. "Grinding stones, nut collection, and origins of sedentism and agriculture in prehistoric China" (in Chinese), in *Essays for the celebration of Ping-ti Ho's 90th birthday*. Edited by Editorial Board, pp. 105–32. Xian: Sanqin Press.

Liu, L., S. Bestel, J. Shi, Y. Song, and X. Chen. 2013. Paleolithic human exploitation of plant foods during the last glacial maximum in North China. *Proceedings of the National Academy of Sciences* 110:5380–85.

Liu, L., J. Field, R. Fullagar, C. Zhao, X. Chen, and J. Yu. 2010. A functional analysis of grinding stones from an early Holocene site at Donghulin, North China. *Journal of Archaeological Science* 37:2630–39.

Liu, L., W. Ge, S. Bestela, D. Jones, J. Shi, Y. Song, and X. Chen. 2011. Plant exploitation of the last foragers at Shizitan in the Middle Yellow River valley, China: Evidence from grinding stones. *Journal of Archaeological Science* 38:3524–32.

Lourandos, H. 1997. *Continent of hunter-gatherers*. Melbourne: Cambridge University Press.

Lu, H., J. Zhang, K. Liu, N. Wu, Y. Li, K. Zhou, M. Ye, T. Zhang, H. Zhang, X. Yang, L. Shen, D. Xu, and Q. Lia. 2009. Earliest domestication of common millet (*Panicum miliaceum*) in East Asia extended to 10,000 years ago. *Proceedings of the National Academy of Sciences (USA)* 106:7367–72.

Lu, T. L. 2013. *Rice planting and evolution of prehistoric cultures*. Beijing: Science Press.

Lupo, K. D., J. M. Fancher, and D. N. Schmitt. 2013. The taphonomy of resource intensification: Implications of resource scarcity among Bofi and Aka forest foragers for the zooarchaeological record. *Journal of Archeological Method and Theory* 20(3):420–77.

Mei, H. 2007. *Transition from Paleolithic to Neolithic in the Nihewan Basin: A study of the discoveries from Yujiagou site* (in Chinese). Ph.D. dissertation, School of Archaeology and Museology, Beijing University, Beijing.

Neimenggu [Neimenggu Wenwu Kaogu Yanjiusuo]. 2004. *Baiyinchanghan: The excavation report of a Neolithic site* (in Chinese). Beijing: Science Press.

Pang, J., C. Kluetsch, X. Zou, A. Zhang, L. Luo, H. Angleby, et al. 2009. MtDNA data indicates a single origin for dogs south of Yangtze River, less than 16,300 years ago, from numerous wolves. *Molecular Biology and Evolution* 26:2849–64.

Pei, W. Z. 1939. *The upper cave industry of Choukoutien*. Beijing: Peking Geological Survey of China.

Piperno, D. R., and D. M. Pearsall. 1998. *The origins of agriculture in the lowland Neotropics*. New York: Academic Press.

Price, T. D. 1987. The Mesolithic of western Europe. *Journal of World Prehistory* 1:225–306.

Redding, R. W. 1995. "Preliminary report on faunal remains recovered from the 1993 excavations," in *Origins of rice agriculture: The preliminary report of the Sino-American Jiangxi (PRC) Project SAJOR*. Edited by R. S. MacNeish and J. Libby, pp. 53–68. Publication in Anthropology 13. El Paso: Centennial Museum, University of Texas at El Paso.

Rice, P. M. 1999. On the origins of pottery. *Journal of Archaeological Method and Theory* 6: 1–54.

Richerson P. J., R. Boyd, and R. L. Bettinger. 2001. Was agriculture impossible during the Pleistocene but mandatory during the Holocene? A climate change hypothesis. *American Antiquity* 66:387–411.

Savolainen, P., Y. Zhang, J. Luo, J. Lundeberg, and T. Leitner. 2002. Genetic evidence for an East Asian origin of domestic dogs. *Science* 298 (5598):1610–13.

Shaanxi [Shaanxi Kaogusuo]. 2007. The Longwangchan site in Yicuan County, Shaanxi Province (in Chinese). *Kaogu* 2007(7):3–8.

Shen, L., D. Xu, and Q. Li. 2009. Earliest domestication of common millet (*Panicum miliaceum*) in East Asia extended to 10,000 years ago. *Proceedings of the National Academy of Sciences (USA)* 106:7367–72.

Sheng, L., Zheng, Y., and Jiang, L. 2006. The Early Neolithic Shangshan site, Pujiang County, Zhejiang Province (in Chinese). *Nongye Kaogu* 2006(1):30–32.

Sherrat, A. 1996. "Plate tectonics and imaginary prehistories: Structure and contingency in agricultural origins," in *The origins and spread of agriculture and pastoralism in Eurasia*. Edited by D. Harris, pp. 130–40. Washington, DC: Smithsonian Institution Press.

Shizitan [Shizitan Kaogu Dui]. 2002. The excavation of the Paleolithic site Shizitan (Loc. S14), Ji County, Shanxi Province (in Chinese). *Kaogu* 2002(4):1–28.

———. 2010. The excavation report at Shizitan, Loc. 9, Ji County, Shanxi Province (in Chinese). *Kaogu* 2010(10):7–17.

———. 2011. The Paleolithic site of Shizitan, Ji County (in Chinese). *Zhongguo Wenwu Bao*, Jan. 1.

Smith, B. D. 2001. Low-level food production. *Journal of Archaeological Research* 9:1–43.

Song, G., T. Wang, and H. Jiang. 2011. The archaeological excavation of Kengnan site in Xichuan County, Henan Province (in Chinese). *Zhongguo Wenwu Bao*, Nov. 18.

Sun, B., S. Cui, and L. Yang. 2007. Early Neolithic sites are found in Shandong (in Chinese). *Zhongguo Wenwu Bao*, Aug. 15.

Sun, B., M. Wagner, Z. Zhao, G. Li, X. Wu, and P. Tarasov. 2014. Archaeological discovery and research at Bianbiandong Early Neolithic cave site, Shandong, China. *Quaternary International* 348:169–82.

Thomas, D. H. 2015. "Engineering Alta Toquima: Social investments and dividends at 11,000 feet," in *Engineering mountain landscapes*. Edited by M. Zedeño and L. Schrieber, pp. 133–200. Salt Lake City: University of Utah Press.

Wang, J., X. Wang, and Z. Chen. 1978. Xiachuan culture: The report of field investigation of Xiachuan sites, Shanxi (in Chinese). *Kaogu Xuebao* 1978(3):259–88.

Wang, Y., S. Zhang, W. Gu, S. Wang, J. He, X. Wu, T. Qu, J. Zhao, Y. Chen, and O. Bar-Yosef. 2015. Lijiagou and the earliest pottery in Henan Province, China. *Antiquity* 89:273–91.

Winkler, M. G., and P. K. Wang. 1993. "The Late-Quaternary vegetation and climate of China," in *Global climates since the Last Glacial Maximum*. Edited by H. E. Wright, J. E. Kutzbach, T. Webb, W. F. Ruddiman, F. A. Street-Perrott, and P. J. Bartilein, pp. 221–61. Minneapolis: University of Minnesota Press.

Winterhalder, B., and C. Goland. 1997. "An evolutionary ecology perspective on diet choice, risk, and plant domestication," in *Peoples, plants, and landscapes: Studies in paleoethnobotany*. Edited by K. J. Gremillion, pp. 123–60. Tuscaloosa: University of Alabama Press.

Winterhalder, B., and D. Kennett. 2006. "Behavioral ecology and the transition from hunting and gathering to agriculture," in *Behavioral ecology and the transition to agriculture*. Edited by D. Kennett and B. Winterhalder, pp. 1–21. Berkeley: University of California Press.

Wu, X., C. Zhang, P. Goldberg, D. Cohen, Y. Pan, T. Arpin, and O. Bar-Yosef. 2012. Early pottery at 20,000 years ago in Xianrendong Cave, China. *Science* 336:1696–1700.

Xia, Z., J. Zhang, J. Liu, C. Zhao, and X. Wu. 2011. Analysis and the ecological environmental around 10000 BP in Zhaitang area, Beijing: A case study of the Donghulin site. *Chinese Science Bulletin* 57(4):360–69.

Xie, F., J. Li, and L. Liu. 2006. *The Paleolithic of the Nihewan Basin* (in Chinese). Hebei: Huashan Culture Press.

Yan, W., ed. 2008. *A century of retrospect on Chinese archaeology: The Neolithic period* (in Chinese). Beijing: Kexue Press.

Yang, X., Z. Wan, L. Perry, H. Lu, Q. Wang, C. Zhao, J. Li, F. Xie, J. Yu, T. Cui, T. Wang, M. Li, and Q. Ge. 2012. Early millet use in northern China. *Proceedings of the National Academy of Sciences (USA)* 109:3726–30.

Yi, M., L. Barton, C. Morgan, D. Liu, F. Chen, Y. Zhang, S. Pei, Y. Guan, H. Wang, X. Gao, and R. L. Bettinger. 2013. Microblade technology and the rise of serial specialists in north-central China. *Journal of Anthropological Archaeology* 32:212–23.

Yu, J., C. Li, X. Yang, and J. Li. 1998. The discovery of Zhuannian early Neolithic site, Beijing (in Chinese). *Beijing Wenbo* 1998 (3):2–4.

Yu, P. L. 2009. *Ancient pit cooking in the American Southwest and Pacific Northwest: A study in foraging intensification*. Saarbruecken, Germany: Verlag Dr Muller.

———. 2015. Ethnoarchaeology of foraging and the case of the vanishing agriculturalists in the Amazon Basin. *Journal of Anthropological Archaeology* 38:59–66.

Yuan, J. 2000. "Rice and pottery of 10,000 years ago in Dao County, Hunan," in *Origins of rice agriculture, pottery and cities*. Edited by W. Yan and Y. Yoshinori, pp. 31–42. Beijing: Cultural Relics Publishing House.

———. 2013. *Hunan Jiushiqi Shidai yu Yuchanyan Yizhi* (Paleolithic Age of Hunan and Yuchanyan site). Changsha: Yuelu Shushe Press.

Yuan, J., and J. Li. 2010. A research report of faunal remains found in the site of Nanzhuangtou, Xushui County, Hebei Province (in Chinese). *Kaogu Xuebao* 2010(3):385–91.

Yuan, S., C. Zhao, X. Zhu, J. Yan, Y. and Yan. 1998. Dating and cultural examination of Shizitan, Ji County, Shanxi Province (in Chinese). *Kaogu* 1998(6):57–62.

Zeanah, D. 2004. Sexual division of labor and central place foraging: A model for the Carson Desert of western Nevada. *Journal of Anthropological Archaeology* 23:1–32.

Zhang, J. F., X. Q. Wang, W. L. Qiu, G. Shelach, G. Hu, X. Fu, M. G. Zhang, and L. P. Zhou. 2011. The Paleolithic site of Longwangchan in the Middle Yellow River, China: Chronology, paleoenvironment and implications. *Journal of Archaeological Science* 38:1537–50.

Zhang, W., and J. Yuan. 1998. A preliminary study on the ancient rice excavated from Yuchanyan, Daoxian, Hunan Province (in Chinese). *Acta Agronomica Sinica* 24:416–20.

Zhang X. L., C. Shen, X. Gao, F. Y. Chen, and C. X. Wang. 2010. Use-wear evidence confirms the earliest hafted chipped-stone adzes of Upper Paleolithic in northern China. *Chinese Science Bulletin* 2010, 55(3): 268–75.

Zhang, Z., S. Chen, Q. Liu, and J. Zhou. 1999. "The research of animal groups of Miaoyan cave site in Guilin" (in Chinese), in *Treatises of international conference on Mesolithic culture*. Yingde City Museum, Department of Anthropology, Zhongshan University, and Guangdong Provincial Museum, pp. 196–211. Guangzhou: People's Publishing House of Guangdong.

Zhao, C., J. Yu, and T. Wang. 2003. Important discoveries are made in early Neolithic site Donghulin of Beijing (in Chinese). *Zhongguo Wenwu Bao*, May 9.

Zhao, Z. 1998. The Middle Yangtze region in China is one place where rice was domesticated: Phytolith evidence from the Diaotonghuan Cave, northern Jiangxi. *Antiquity* 72: 885–97.

———. 2000. A study on the rice phytoliths of the Diaotonghuan site (in Chinese). *Zhongguo Wenwu Bao*, July, 5.

———. 2006. "New study on the ancient agriculture in South China," in *Prehistoric archaeology of South China and Southeast Asia*. Edited by Institute of Archaeology CASS, pp. 145–56. Beijing: Cultural Relics.

———. 2011. New archaeobotanic data for the study of the origins of agriculture in China. *Current Anthropology* 52:s295–s306.

Zhao, Z., D. Pearsall, and Q. Jiang. 1995. "Analysis of phytoliths from Xian Ren Dong and Wang Dong," in *Origins of rice agriculture: The preliminary report of the Sino-American Jiangxi (PRC) Project SAJOR*. Pp. 47–52. Publication in Anthropology 13. El Paso: Centennial Museum, University of Texas at El Paso.

Zhenzhou [Zhenzhou Shi Wenwu Kaogu Yanjiuyuan, Beijing Daxue Kaogu Wenbo Xueyuan]. 2011. The major achievements in the excavation of Lijiagou site, Xinmi City (in Chinese). *Zhongyuan Wenwu* 2011(1):4–6, 39.