The Origins of Food Production in North China: A Different Kind of Agricultural Revolution

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By roughly 8,000 calendar years before the present (calBP), hunter-gatherers across a broad swath of north China had begun small-scale farming of broomcorn millet (*Panicum miliaceum*) and foxtail millet (*Setaria italica*).\(^1\)\(^-\)\(^6\) According to traditional wisdom, this early millet farming evolved from the intensive hunter-gatherer adaptation represented by the late Pleistocene microblade tradition of northern China.\(^2\)\(^-\)\(^7\) termed here the North China Microlithic. The archeological record of this hunter-gatherer connection is poorly documented, however, and as a result the early agricultural revolution in north China is not as well understood as those that occurred in other parts of the world. The Laoguantai site of Dadiwan, in the western Loess Plateau, Gansu Province, PRC, furnishes the first complete record of this transition, which unfolded quite differently from other, better known, agricultural revolutions.

Early millet farming is represented by at least five geographically separate but roughly contemporaneous cultural complexes (Xinglongwa, Houli, Cishan, Peiligang, and Laoguantai) distributed over an environmentally diverse area stretching 1,500 km from the northeast China Plain to the western Loess Plateau (Fig. 1). That these complexes appear so close in time but far apart in space and vary so much in cultivar choice and cultural details makes it unlikely that the millet farming revolution of north China was the spread of an idea, crop, or people from a single source. This phenomenon is better understood as an evolutionary contest among many varied regional adaptations, some of them (at least the five above) involving food production, others not. However, all these adaptations are rooted in a trajectory of hunter-gatherer intensification running well back into the Pleistocene.

Unfortunately, the published literature does not present even one continuous stratigraphic sequence or statistically convincing seriation connecting any of the cultural complexes representing north China’s preagricultural hunter-gatherers to any of the five representing its early millet farmers. The traditional view that millet farming evolved from the North China Microlithic is entirely plausible and arguably the most viable scenario, except that its artifact assemblages do not match. Microblades and microblade cores which are common in North China Microlithic sites (such as Xiahuan, Xueguan, Shizifan, Shayuan, and Hutouliang), are rare or absent in nearby early millet farming sites such as Cishan, Peiligang, and Dadiwan.\(^7\)\(^-\)\(^9\) To date, not one stratified assemblage or series of related assemblages bridges this technological gulf.

In this and other key respects, the agricultural transition in north China is unlike the better-known transitions of the Near East\(^10\)\(^-\)\(^19\) and Mesoamerica,\(^20\)\(^-\)\(^27\) where archeological continuities make the forager to farmer connection much easier to trace. We argue here that this difference is not an artifact of archeological bias, preservation, or sampling, although those have muddied the water. Rather, using a combination of optimal foraging and evolutionary game theory, we construct a model that explains the disconnection between forager and millet farmer in north China as the signature of an agricultural transition quite different from those more richly and continuously attested to elsewhere around the globe. To support that argument, we report recent work at the Dadiwan site, which provides the first complete archeological sequence from north China to record behavioral variation across the transition to agriculture. While controversial and certainly far from conclusive, our model matches the Dadiwan record on key points much more closely than does any alternative account of the transition to millet agriculture in North China.

The Dadiwan record begins at about 60,000 calBP, revealing a history of use by human hunters throughout the...
late Pleistocene into the Holocene. The record spans the transition to intensive hunting and gathering, then to incipient or low-level millet agriculture, and finally to intensive millet agriculture. These data show that the intensive hunter-gatherer adaptation from which low-level Laoguantai millet agriculture evolved had its roots in the North China Microlithic, as long supposed, but suggest that this adaptation did not develop at the Dadiwan site itself. Instead, it came into the western Loess Plateau with North China Microlithic groups migrating south from sandy deserts along the upper Yellow River. This is why evidence of the millet farming transition is so difficult to find within the Loess Plateau. The upper Yellow River desert version of the North China Microlithic featured small, highly mobile hunting groups that are difficult to detect in the archeological record. Maintaining this adaptation as they moved south required smaller social units, more frequent residential moves, and extreme conservation of traditional weaponry made from raw materials largely unavailable in the Loess Plateau, to the point that they left almost no archeological record at all. However, these same circumstances encouraged social and behavioral innovation, increased regional adaptive variability, and hastened the transition first to incipient and later to intensive agriculture. From the initial appearance of domesticated millet to a fully agricultural millet-based economy took just over 1,000 years at Dadiwan, much less time than similar transitions required in the Near East and Mesoamerica, less indeed than had Dadiwan’s own preagricultural populations been larger, stable, and more densely settled.

**OBSTACLES TO AGRICULTURE**

Agriculture is so elemental to modern life that it is easy to forget just how recently it developed. Humankind has been making tools for something like 2,500,000 years, building fires for perhaps 500,000 years, and communicating via spoken languages for at least 50,000 years, but growing crops and tending livestock for scarcely more than 10,000 years, only since the end of the Pleistocene. Various forces drive this time line, most notably the conditions and behaviors that had to be in place before these ground-breaking innovations could develop. From this perspective, agriculture appears to be especially demanding, evolving only with difficulty and thus relatively late in time. Agricultural systems are evidently hard to get started, hard to maintain, or both.

Early anthropology argued strongly for the first (hard to get started), and laid this mainly to primitive naïveté about the environment; Pleistocene hunter-gatherers were unable to understand that plants grow from seeds. Once the plant-seed connection was understood, early scholars held, the productive superiority of agriculture caused its rapid adoption and spread. That account is flawed: Ethnographic hunter-gatherers clearly grasp the plant-seed connection without turning it to use in producing food. Nevertheless, it is probably true that human culture and cognition were inadequate for the development of agriculture until about 50,000 calBP. At that time, however, and for the next 40,000 years or so, environment made anything of the sort impossible, human IQ notwithstanding. The CO₂-depleted late Pleistocene atmosphere limited the productivity, and hence human use of plants. Late Pleistocene climate switched rapidly from glacial to interglacial conditions within centuries or even decades, requiring near-continual adaptive reorganization, rendering information learned about plant use in one generation essentially useless in the next. A combination of physiology, culture, and environment thus prevented humans from acquiring the knowledge and behaviors essential to intensive plant use and from channeling these into successful experiments with agriculture until the close of the Pleistocene and the end of the Younger Dryas, about 11,600 years ago. Even with all these critical external and internal forces favorably aligned, agriculture developed only rarely in the Holocene.

In all, agriculture managed to evolve and take firm hold only a dozen or so times, the most successful forms spreading from just a handful of independent centers around the globe to cover much, although certainly not all of it, at least not until recently. At the time of Columbus, fully a quarter of the world remained hunter-gatherer, even in places that are today leading agricultural producers, such as California, Argentina, and Australia, where one might logically expect agriculture to have evolved, or into which it should easily have spread. The evolutionary obstacles accounting for this checkered global trajectory seem likely to explain why, even in places like the Near East and Mesoamerica, where intensive full-time agriculture would eventually climax on a massive scale in the premodern world, the transition was drawn out over three to five thousand years of what is termed *low-level food production*, during which agriculture was never pursued on a scale large enough to disrupt preexisting
As modeled by Winterhalder and Belovsky, the cost of hunting and gathering, and thus its relative advantage over food production, waxes and wanes in 50- to 90-year stable limit cycles. These cycles rise and fall almost, but not quite inversely with hunter-gatherer population size, the qualification arising from the fact that lag time is built into the process. In the first half of each cycle, human population rises, initially because resource populations are large relative to demand and subsequently because internal group dynamics keep these populations rising even as resource abundance falls (Fig. 1). In the second half of the cycle, human populations fall, initially because resource populations are small relative to demand and subsequently because internal group dynamics keep these populations falling even as resource abundance increases. Wild resource return rate, the variable indexing the cost of hunting and gathering, lags just slightly behind wild resource population size. Return rates are lowest when wild resources are scarce relative to demand (indicated by arrows in Fig. 1), during which times hunter-gatherers should turn to the most costly wild resources and experiment with food production.

The more a resource is taken, the less of it there is to go around, so time spent acquiring it will increase, causing its overall return rate to decrease. Foragers dependent on that resource may counter by increasing foraging time, but since there is less food to go around, ultimately there will be fewer foragers too. As forager population falls, however, the depleted resources have a chance to recover. Once the forager population has become sufficiently small and the wild resource population sufficiently large, the situation again reverses: Foraging population grows and resource abundance shrinks. First Winterhalder, then Belovsky showed that hunter-gatherer populations, subsistence resources, and associated return rates should vary precisely in this way, in what are termed stable limit cycles (Box 1). It is easy to see, however, that with only these forces in play there is virtually no chance that using costly wild resources or producing food will intensify or even persist. By the time return rates fall enough to make costly wild resources and food production cost-effective, human population (demand) is already falling and resource population (supply) is rebuilding. In a short time, high-quality wild resources will be cheaper to target than will low-quality wild resources, and less costly than food production. Small-scale experiments with food production thus might come and go over a very long time without ever edging any closer to intensive, full-time agriculture. This relationship explains the temporal persistence of low-level food production in the Near East, Mesoamerica, and even eastern North America.

Clearly, the driver of hunter-gatherer subsistence intensification does not just make traditional staples more costly; the human population can simply shrink to compensate. Things that make previously costly resources cheaper are more promising, but are mainly special cases, such as climate change or beneficial genetic mutations. In the last instance, the most powerful and general trigger for hunter-gatherer and early agricultural intensification is not change at the production end of

Box 1. Stable Limit Cycles

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things, but of the distribution end, where a simple shift in social relations can reverse existing cost structures, making traditional resources more costly and previously costly resources cheaper.

Variation in social relations causes hunter-gatherers to distribute resources in two quite different ways. Among what Woodburn termed immediate-return hunter-gatherers, there is no storage, so the day-to-day uncertainties of hunting and gathering require unfettered access to territories and their resources, as well as widespread intragroup sharing of harvested resources. Lucky and unlucky foragers pool and evenly split their take. Here the attitude is that land and resources are public goods, belonging to everyone. Resources should be freely used, redistributed, and shared to equalize disparities; society should punish those who hoard. In contrast, delayed-return hunter-gathers accumulate and store some resources for future use and thus place limits on their immediate consumption, often by privatization, making them the property of those who obtained them. Here the attitude is that resources belong exclusively to those who obtain them and society should punish those who take resources garnered by others without permission.

These contrasting conventions have important implications for subsistence intensification. The "open field, common pot" version discourages intensive foraging and even modest levels of food production, which are so costly that individuals will not risk them without assurance that they can keep everything they harvest. That is, they need some assurance that the very low returns they obtain will be safe from claims of ne'er-do-wells, who work less than, but always receive the same share as everyone else. If resources must be split with freeloaders, harvesters of low-return resources may well end up expending more energy than they obtain. For this reason, immediate-return hunter-gatherers generally restrict themselves to resources having returns high enough to offset freeloader overhead, using just enough low-return resources to squeeze by and punishing those who hoard them. This keeps population size and density low. By contrast, because they are protected from freeloaders, delayed-return hunter-gathers frequently target low-return resources, especially plants that are easily stored. This sustains larger, denser, and more stable populations while reducing the payoffs to individuals who continue to specialize in high-return resources, use of which can be sustained only by sharing.

It follows that a shift away from a convention that treats resources as public property to one that treats them as private property might spark a previously frustrated trajectory of intensification and growth, leading to intensive hunting and gathering, low-level food production, and eventually intensive agriculture. Circumstances, however, frequently work against this happening. Hunter-gatherers are widely touted as socially flexible pragmatists, skilled at bending and breaking rules for a wide range of cultural behaviors, including political leadership, marriage, and postmarital residence. But this flexibility does not apply to resource use rights, where flexible ground rules are worse than none at all. Groups may have different rules for different resources, as for example in the aboriginal western U.S., where large game was nearly always a public good but plants nearly always private. Flexible resource use rights, however, amount to different rules for the same resource. This is a surefire recipe for conflict, with individuals acting correctly under one set of rules but being punishable as deviants under another. In this sense, the conventions of resource distribution and use rights generate what are termed frequency-dependent payoff structures that strongly favor sticking to an existing set of rules even if they are suboptimal.

An analogy here is the convention of driving on the left- or right-hand side of the road: It matters less what people do than that they agree, which they always will because the driving environment favors whichever rule is in the majority. If more than 50% of the population drives on the right or left, the only sensible thing to do is drive on the favored side, so nearly everyone will. Resource use rights differ mainly in that, as we have seen, when populations are large privatization produces higher fitness payoffs than does generalized sharing. Still, frequency dependence will always make achieving these higher payoffs a group-level problem of coordination. The pattern of resource hoarding (storage) and privatization needed for agriculture to be viable cannot evolve piecemeal, one forager at a time, within a system where sharing is the norm, any more than a convention of driving on the left can evolve piecemeal, one driver at a time, within a system where driving on the right is the norm.

Frequency dependence thus makes conventions of resource distribution and use conservative and resistant to change, as are subsistence patterns with payoffs that hinge on these conventions. Even if population crowding and resource depression favor broadening diet to include more costly subsistence practices like plant tending, enforced resource sharing and punishment of hoarding will discourage that until a sufficiently large fraction of the population simultaneously rejects the prevailing sharing rule and adopts its opposite. Food...
production requires this rule shift, which protects the labor investment of those who target and store more costly resources and punishes those who target only high-quality resources, do not store, and insist that others share. Variation in group size provides perhaps the greatest latitude for achieving this shift. Large groups impede social change because many individuals must simultaneously switch conventions; in smaller groups, fewer individuals can tip the balance, so the probability of change increases simply as a function of sampling error. This means that anything that reduces social contact or group size will facilitate convention shifting. For agricultural transitions, this shift is from a sharing system that discourages intensive use, storage, and tending of plants to a privatized system that encourages all three.

**ARCHEOLOGICAL IMPLICATIONS**

These relationships have important implications for the archeological record. All else being equal, the quality of the archeological record should be good, with more sites having richer deposits, where populations are relatively large, dense, and restricted in space. Such conditions favor the status quo in social relations and work against restructuring coordinated behaviors like those governing resource ownership. Conversely, and again, all else being equal, the quality of the archeological record will be poor, with fewer sites having sparser deposits, where population is small, scattered, and mobile. These conditions promote restructuring of frequency-dependent social coordinations. This is broadly in accord with what we know about the pace of agricultural intensification and the quality of the archeological record in different centers of early agriculture around the world. Intensification and change are slow, taking thousands of years in the Near East and Mesoamerica, where the archeological record is good, with many sites and solid sequences. In contrast, agricultural intensification appears to have taken only a third of the time, just over 1,000 years from start to finish, in the early millet center of north China, where the archeological record is sketchy, with few sites and major cultural discontinuities. The Dadiwan site, which provides the first complete record of this anomalously rapid north China agricultural transition, furnishes support for this latter, faster mode of agricultural intensification and its connection to a small, dispersed, highly mobile hunter-gatherer population.

Dadiwan shows that what makes early millet farming different, at least in the western Loess Plateau, is a transformation of intensification that did not unfold in situ but over space as the result of early Holocene population budding and migration south out of the main distribution of the North China Microlithic. The North China Microlithic most likely represents a hunting adaptation centered on large game that required moving camp often enough and over distances long enough to preclude effective storage in a delayed-return economy. It was, by necessity, an immediate-return economy, dependent enough on sharing to discourage intensification. Groups along its more mesic southern margin, however, encountered both novel adaptive challenges and increasing opportunities for plant use, and were fragmented into small, thinly spread social units predisposed to the kind of social innovations needed to encourage costly experiments with plant use, storage, and tending. These specialized hunters had either shifted or expanded south, replacing more generalized hunter-gatherers in the sandy deserts along the upper Yellow River, at the beginning of what is termed the Tengger Period (12,800–11,500 calBP). They may have begun experimenting with plant tending there, but more likely did so when they moved further south, and probably not in earnest much north of the western Loess Plateau and Dadiwan itself. Data obtained in connection with our research are in keeping with “Romer’s rule” that major innovations are conservative, permitting persistence of an existing adaptation despite changing circumstances: Laoguantai millet agriculture was the experiment of hunters interested in feeding not only themselves, but their hunting dogs, which became increasingly important as the scene of animal procurement shifted from the open sandy deserts of the upper Yellow River to the gallery forests that characterize the western Loess Plateau.

Lasting no more than 700 years, the Laoguantai food production experiment at Dadiwan was just one of a wide range of such trials across north China, all but one equally short-lived. That one arose in some as yet unknown location and rapidly morphed into the intensive agricultural pattern known as Banpo, the initial phase (ca. 6,800–5,700 calBP) of the Yangshao techno-complex (ca. 6,800–4,900 calBP) recognized throughout the Yellow and Wei River drainage. The number and diversity of these short-lived agricultural experiments and the rapid ascendance of the Banpo variant attest to a cultural setting that was unusually favorable to experiments in subsistence intensification, including low-level and intensive food production, likely for the reasons just outlined. In north China, the initial experiments with food production began with small, highly mobile hunting groups that could easily recoordinate subsistence and society in response to early post-Pleistocene climate change and population growth.

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THE DADIWAN SITE

The Dadiwan site (105.904°E, 35.015°N) in Shao Dian Village, Qin’an County, Gansu Province, PRC, is the oldest known example and type site of the initial or Dadiwan Phase of the Laoguantai cultural complex, the westernmost expression of early millet agriculture in north China.

The site is in the Longxi-Jingning Basin on the southern margin of an east-west trending valley centered on the Qing Shui River (Fig. 1). The original excavations revealed a five-component cultural sequence, starting with a basal Dadiwan Phase of the Laoguantai horizon (7,800–7,300 calBP) that featured scattered dwellings, and low-fired Dadiwan-type ceramics. Scanty remains of domesticated broomcorn millet (Panicum miliaceum) indicated an occupation by low-level food producers.

This occupation was followed by, but clearly separated in time from (and thus not the source of) a Late Banpo (Early Yangshao) occupation (6,500–5,900 calBP). That occupation featured a settlement-surrounding moat, crowded square dwellings, hard-fired Banpo type ceramics, and abundant remains of both domesticated foxtail and broomcorn millet (Setaria italica, Panicum miliaceum) indicating intensive, fully developed agriculture. From then on, occupation was mainly for special nonresidential purposes and was more or less continuous through the Middle (“Miaodigou”, 5,900–5,500 calBP) and Late (5,500–4,900 calBP) phases of the Yangshao tradition. A single post-Yangshao component (Chang Shan, 4,900–4,800 calBP) was short-lived and limited in size. As with all known early millet sites in north China, no earlier preagricultural components were found. However, surveys near Dadiwan in 2002 recorded a late Pleistocene archeological complex characterized by crude quartz flakes and shatter we now term Zhuang Lang–Tong Xin (ca. 32,000–18,000 calBP), which limited subsurface testing in 2004 indicated was present at Dadiwan itself. This prompted us to secure permission to conduct additional excavation at Dadiwan in 2006 to explore the technological and cultural relationship between this Pleistocene complex and Dadiwan’s previously documented agricultural components. We complimented this with a study of subsistence changes attending the transition to agriculture, using stable isotope analysis of human and animal bone from the original excavation and our 2004 and 2006 Dadiwan excavations.

Because Dadiwan is a protected national landmark and its cultural deposit turned out to be extremely deep, our 2006 work was limited in area. In total, we excavated 19.5 m³ of deposit, reached the base of the cultural deposit at 7.1 m, and extended the culturally sterile loess section and its paleoclimatic record to 8.5 m (Fig. 2). Artifact distributions (Fig. 3) justify dividing the 6.6 m of the 2006 cultural deposit into a six-component sequence (Fig. 4). A total of 88 radiocarbon dates are available for Dadiwan. Chronological anchors for the 2004 and 2006 excavation units include 20 radiocarbon dates by AMS and 5 optically stimulated luminescence dates. Rejecting those that are obviously stratigraphically reversed, these dates define a robust cultural sequence that is strongly supported by observed changes in artifact frequency attributable to dated climatic events (Last Glacial Maximum, Younger Dryas).

Ceramics

Typable sherds of three successively older wares (Late Yangshao, Late Banpo, and Dadiwan) indicating the top two components correspond to ceramic occupations recognized during previous excavations: early incipient Dadiwan Phase farmers (Component 5) and later intensive Late Banpo Phase farmers (Component 6). A dra-
matic drop in sherd count and density places the ceramic-preceramic transition at the base of Component 5 (Fig. 3). The small sample of sherds recovered below that, from Components 3 and 4, is statistically indistinguishable from the ceramic assemblage of Component 5 and surely the result of downward stratigraphic mixing. The dominant flake-and-shatter lithic technology produced simple tools by direct and bipolar hard-hammer percussion on locally abundant quartz river cobbles, yielding roughly equal amounts of flakes and shatter and virtually no cores (Fig. 5). This assemblage is indistinguishable from the percussion quartz technology that characterizes the late Pleistocene "flake tool" technology seen across much of northern China throughout the Middle and Upper Pleistocene. Our Dadiwan data show that this complex was in place in the western Loess Plateau by 60,000 calBP and persisted much longer than is generally accepted, at least into the Late Banpo Neolithic. Tiny microblades and microblade cores fashioned predominantly from small pieces of nonlocal cryptocrystalline chalcedony identify a second, very different lithic technology that is obviously derived from the North China Microlithic. The miniature microblade cores include the wedge- and boat-shaped variants noted elsewhere in northern China. They are triangular in cross section and vary in taper to take maximum advantage of raw material (Fig. 5). The microblades at Dadiwan are correspondingly small, and while they are mainly core preparation and maintenance waste, those taken away and used could not have been much larger. The original excavation at the Dadiwan site produced fewer than 10 microblades, all larger, of different materials, and from post-Laoyuantai components. However, it also yielded numerous thin, tabular bone handles with lateral margins finely slotted to accept very small microblade insets of the scale we recovered. This microlithic technology is concentrated in Component 5 (Fig. 3), but clearly present in situ in Component 4, in which the lithic assemblage is statistically...
distinct from that of Component 5 and clearly not a product of downward mixing.51,54

Stable Isotopes

Biochemical analysis of stable isotope concentrations ($\delta^{13}C$ and $\delta^{15}N$) in Holocene animal bone provides a rare glimpse of the initial transition to low-level food production during the Dadiwan Phase of the Laoguantai tradition and its difference from Late Banpo intensive agriculture. These changes produced an isotopic shift in the two most important domesticates at Dadiwan, dogs (Canis familiaris) and pigs (Sus scrofa), from individuals characterized by low $\delta^{13}C$ and $\delta^{15}N$, indicating consumption of a wild diet, to increasingly domesticated individuals characterized by high $\delta^{13}C$ and $\delta^{15}N$ (Box 2). Isotopic values for wild herbivores (red deer, Cervus elaphus; sika, Cervus nippon; musk deer, Moschus sp.; aurochs, Bos sp.) recovered from the Dadiwan site establish a baseline for the “wild diet signature” of low $\delta^{13}C$ and $\delta^{15}N$ (Fig. 6). In comparison, the values for dogs and pigs are more varied and suggest that millet farming during the Dadiwan Phase (Component 5) was the innovation of a hunting group that had domesticated dogs but not pigs. While all Dadiwan Phase pigs are wild (low $\delta^{13}C$, $\delta^{15}N$), the isotopic values for Dadiwan Phase dogs are dichotomous, representing wild (low $\delta^{13}C$, $\delta^{15}N$) individuals and what clearly are domesticated (high $\delta^{13}C$, $\delta^{15}N$) individuals.

Since dogs were the only domesticated animals in the early Dadiwan Phase system and consumption of wild game (pigs and herbivores) would not produce the elevated values of $\delta^{13}C$ they display, these dogs had to have been rationed with a combination of wild meat and cultivated millet. We lack isotopic data for the Dadiwan Phase humans who fed these dogs, but it seems unlikely they would have been able to do so unless they enjoyed a diet that was as least as rich in meat relative to plants and cultivated millet relative to wild plants (high $\delta^{13}C$, $\delta^{15}N$). They also would have been unlikely to have done so unless Dadiwan Phase low-level millet farming served a hunting adaptation that targeted closed habitats where domesticated dogs were needed to point, flush, drive, or tree game, while demanding enough residential mobility to preclude the domestication of pigs. Intensive Late Banpo (Early Yangshao) farming did not directly evolve from low-level Dadiwan Phase farming and was much closer to the farmer end of the forager-farmer spectrum. However, hunting remained important, as abundant remains of various artiodactyls, such as sikas show.50 In addition, while all of Dadiwan’s Yangshao dogs were domesticated, presumably for hunting, its Yangshao pigs range gradually from fully domesticated to completely wild, the latter taken as wild prey.49

DADIWAN CULTURE HISTORY

That Dadiwan was occupied by at least 60,000 calBP raises the possibility that its earliest occupants were archaic Homo sapiens. The lowest Components 1–3 shed little light on the many controversies surrounding the archaic-to-modern-human transition in this part of the world but do establish the longstanding dominance of percussion technology and quartz as a raw material. Whether modern Homo sapiens developed this flake-and-shatter lithic technology elsewhere or locally or borrowed it from their archaic precursors, they maintained and used it almost exclusively for at least another 20,000 years, during which it changed little except in abundance, likely reflecting human responses to climate change. Strikingly low artifact densities in Component 3 (Fig. 3), for example, seem to reflect near-total abandonment of the site, likely due to deteriorating environmental conditions associated with a cold, dry Last Glacial Maximum (LGM). A less marked decrease at the top of Component 4 and base of Component 5 probably corresponds to the Younger Dryas climatic reversal.

In contrast to flake-and-shatter quartz, Dadiwan microblade technology is recent and intrusive, postdating the LGM. Several lines of evidence indicate that the fine-grained raw material (cryptocrystallines) it required was exceedingly scarce, making its local development unlikely. There is no known natural source of this material within the Longxi Basin itself. Local farmers and shepherds know of none, while field inspection of 654 separate locations has failed to locate any. Indeed, cryptocrystallines are represented in only 3 of the 167 sites we have located since 2002, in each case by a single artifact.53,63 It is clear, nevertheless, that the North China Microlithic hunters who made their way south to the western Loess Plateau and to Dadiwan valued microblade technology enough to obtain cryptocrystallines by trade or travel from so far away that there was never...
enough to satisfy demand, the material being constantly in short supply (Box 3). Without the necessary raw material anywhere nearby, the Dadiwan area is not one in which microlithic technology would likely develop or to which it would easily diffuse by cultural transmission. Instead, microlithic technology was brought to Dadiwan physically, by groups moving south from the main distribution of the North China Microlithic.

All of this is consistent with our hypothesis that the first part of the trajectory leading to agriculture at Dadiwan actually took place 300–400 km to the north, with the Tengger Period expansion of the North China Microlithic into the upper Yellow River and adjacent deserts (Fig. 1) shortly before the end of the Pleistocene. The next part occurred during brief but severe cold-dry episodes, including the Younger Dryas, when the upper Yellow River environment deteriorated enough to push small groups of these intensive microlithic hunters still further south, eventually into the upper Wei River drainage. This is represented at Dadiwan by the initial appearance of microlithic technology in Component 4, which is essentially a prepottery microlithic, dominated by the older quartz flake-and-shatter lithic technology.

The final part of the trajectory leading to agriculture is signaled by the appearance of Dadiwan-type Laoquantaí ceramics in Component 5, which represents a fully developed ceramic microlithic, dominated by microlithic technology. Toward the end of this period, certainly by 8,000 calBP, the transplanted intensive hunter-gatherers at Dadiwan either began or continued experimenting with low-level millet agriculture, growing increasingly reliant on it through time. Domesticated broomcorn millet (Panicum miliaceum) appears in the archeological record and was being used to feed hunting dogs by 7,500 calBP. Microblade technology declined relative to quartz flake-and-shatter technology toward the end of Component 5. After a brief hiatus, during which the evidence for low-level food production disappeared from the upper Yellow Plateau, the Dadiwan site was reoccupied during the Late Banpo Phase, represented in Component 6, almost certainly by immigrants from further east where the Early Banpo Phase is represented. For the first time, ceramic technology overshadowed lithic technology, and the microlithic technology all but disappeared. These changes likely reflect the diminished importance of foraging and especially hunting, relative to farming, which had by then become an intensive, full-time pursuit.

Box 2. Stable Isotopes $^{13}$C and $^{15}$N

Skeletal concentrations of $^{13}$C (measured relative to a standard and reported as $\delta^{13}$C) vary according to the kind of plants that are consumed. While the natural vegetation of the prehistoric Loess Plateau was dominated by what are termed C$_3$ plants, which have low $\delta^{13}$C values, the two important north China domesticated millets, broomcorn millet (Panicum miliaceum) and foxtail millet (Setaria italica) are C$_4$ grasses with high $\delta^{13}$C values. This isotopic difference registers in the skeletons of humans and animals that consumed plants or animals that eat plants. Low $\delta^{13}$C values reflect plant consumption limited to what was available in the natural Loess Plateau environment; high $\delta^{13}$C values reflect the heavy consumption of millet, which was rare in the wild, so that its availability had to have been augmented by human planting, tending, and storage. Previous archeological work in north China seals this isotopic connection. Humans with high $\delta^{13}$C values either stored and consumed large quantities of millet or kept and consumed animals having $\delta^{13}$C values that were elevated as a consequence of having been provisioned with millet grain, millet hay, and/or the meat or waste of animals with $\delta^{13}$C values elevated for the same reason. Identification of millet consumption in north China is therefore similar to the isotopic identification of maize consumption in the New World. maize also being a C$_4$ grain with high $\delta^{13}$C values.

Concentration of $^{15}$N, again reported relative to a standard as $\delta^{15}$N, provides another, quite different line of dietary inference. Because $\delta^{15}$N is enriched by approximately 3% at each trophic level in the food chain, the averaged $\delta^{15}$N signal of an organism indexes its position in that food chain. Nitrogen values can be difficult to interpret, but herbivores at the bottom of the food chain should display low $\delta^{15}$N values and herbivore-eaters noticeably higher $\delta^{15}$N values. For dogs and pigs, ascending the early farming food chain meant becoming more heavily dependent on domestic sources of protein such as meat table scraps, offal, and miscellaneous domestic waste, including human feces, elevating their skeletal $\delta^{15}$N. Pigs and dogs that consumed meat scraps or domestic waste from animals fed with millet grain or hay, or that had a diet that was independently supplemented with millet grain as slop or table scraps, should also have elevated $\delta^{15}$N levels. As a result, the trajectory of including dogs and pigs in the early web of food production at Dadiwan ought to be indicated by a shift from wild types characterized by low $\delta^{13}$C and $\delta^{15}$N to domesticated types characterized by high $\delta^{13}$C and $\delta^{15}$N.

SUMMARY AND IMPLICATIONS

The 2006 Dadiwan excavations document an archeological record that runs from 60,000 calBP to at least 5,700 calBP, with components representing nonintensive hunter-gatherers (Components 1, 2, 3), intensive hunter-gatherers (Component 4), low-level Dadiwan Phase farmers (Component 5), and intensive Late Banpo Phase millet agriculturalists (Component 6), stratified in what is the first complete foraging-to-farming sequence for north China. Length of record aside, this agricultural transition is quite unlike those documented in Mesoamerica and the Near East, where the forager-farmer transition proved easier to demonstrate because foraging groups left a much richer archeological record of a much slower transition. Dadiwan’s foraging groups were small, highly mobile bands of hunters that had splintered from the main body of the North China Microlithic in the upper Yellow River deserts and worked their way south into the more heavily vegetated and topographically complex western Loess Plateau. Here, hunting dogs and substantial
seasonal movements were required to map onto the highland to lowland, north to south migration of game. Millet consumption and later planting flourished in this context, probably by providing an alternate food that promoted greater stability in what had been an exceedingly mobile settlement system.

One presumes that the combination of low population densities and dependence on game with widely separated summing and wintering grounds required frequent and long moves to track the migration of game and find potential mates. This, in addition to their diminutive lithic technology, is why these groups have remained archeologically invisible for so long: They moved too fast to leave a significant archeological record or detectible radiocarbon footprint. North China has relatively few sites dated between 11,500 calBP and 8,500 calBP, the two closest of which, Pigeon Mountain and Shuidonggou, are microblade sites on the upper Yellow River, 350 km to the north of Dadiwan. Indeed, while artifact distributions show that Dadiwan itself was continuously occupied during this time, its use was evidently so ephemeral that middens did not accumulate and very little carbon was either produced or preserved. Like previous Dadiwan investigators, we could find no charcoal of any size in any context dating to this interval. While frustrating, this radiocarbon gap tells us something important, that the landscape on which Dadiwan Phase millet agriculture evolved was sparsely populated, with very small, very mobile hunter groups.

Recently reported evidence from the 10,000-year-old occupation at the site of Cishan on the North China Plain, 750 km east of Dadiwan, may provide tantalizing insights about this little-known period. While the large volume of broomcorn millet found in its storage pits has been interpreted as representing the work of farmers, the uncarbonized millet remains and intact (unopened) storage pits attest to a pattern of caching large quantities of unused millet. This almost never happens with full-time sedentary farmers who sooner or later end up eating or otherwise disposing of what they store (for example, by feeding it to livestock). It is uniquely characteristic, however, of subsistence intensification among mobile hunter-gatherers, which begins with the expedient caching of resources in bulk whenever they are abundant and cheaply obtained. Representing so little investment, such caches are readily abandoned if prospects look better elsewhere. Such unopened caches are visible in the archeological record of prehistoric gathering economies from Central California, to eastern North America, and perhaps even coastal southern China. That Cishan represents such a pattern is uncertain but cannot be discounted, since the cached broomcorn millet may well be wild, not domestic or even cultivated. At any rate, this scenario captures the kind of highly mobile hunter-gatherer adaptation in which experiments with millet tending likely began in the Dadiwan area. In contrast to this highly mobile pattern, the early agricultural adaptation at Dadiwan was stable enough to produce a detectable carbon signature, but groups remained small and regional population densities extremely low, so that Laoguantai components as a whole are also exceedingly rare. There are only four other Laoguantai components in the whole of Gansu Province. Extensive survey and excavation has failed to produce even one, apart from Dadiwan itself, in the eastern Longxi Basin. The nearest well-studied Laoguantai neighbors, Xishanping, Beishouling, and Guantaoyuans, are 60–140 km to the south and demonstrably younger.

A point made earlier is that the upside to systems made up of small, thinly spread groups is the latitude they provide for major adaptive shifts in behaviors that have frequency-dependent payoffs; they can more easily and rapidly shift from the convention that resources are private goods, which discourages intensification and experiments with food production, to the convention that resources are public goods, which encourages both. This likely explains the relatively rapid transition to food production at Dadiwan and probably at the four other culture complexes in which early millet farming appears at about 8,000

Figure 6. Stable isotope chemistry of Dadiwan fauna. The Dadiwan Phase of the Laoguantai tradition corresponds to Component 5 in Figures 3 and 4; Yangshao with Component 6 and later occupations. Ungulates, including Cervus sp, Moschus sp, and Bos sp, but not pigs, come from both periods. All Dadiwan Phase pigs display a "wild" signature (low δ¹³C, δ¹⁵N) identical to the wild-foraging ungulate herbivores. Dadiwan Phase dogs, however, are dichotomous, representing wild (low δ¹³C, δ¹⁵N) and clearly domesticated (high δ¹³C, δ¹⁵N) individuals. These data strongly suggest that Dadiwan Phase millet agriculture evolved in a hunting context that required flushing dogs and was too mobile to permit pig domestication.
Demonstrating that the raw materials essential to microlithic technology were scarce or entirely absent in the western Loess is critical to the argument that the technology is exotic. The presence of such technology due to an influx of North China Microlithic populations from the north, where the technology and necessary raw materials are common, would imply that these migrants were responsible for the development of Laoguantai millet agriculture. Miniaturization of the technology, indicating that tools were saved and used well beyond the normal point of discard, is perhaps the strongest evidence that the fine-grained cryptocrystallines essential to microblade production were extremely scarce in the western Loess Plateau. The microblades and microblade cores in the 2006 Dadiwan sample are among the smallest on record anywhere. Averaging just 9.0 mm in length, the microblades are only two-thirds the size of microblades found in North China Microlithic sites on the upper Yellow River and from the North American Arctic and Subarctic.

Similarly, the microblade cores, which average just 10.6 mm in height from platform to base, are less than half the size of the smallest Neolithic specimens reported from deserts to the north and from the North American Arctic and Subarctic.

The cryptocrystalline demand-supply problem is independently demonstrated in the relationship between the size and raw material composition of lithic assemblages. In this case, assemblage size roughly measures demand for stone tools, while raw material composition of lithic assemblages (quartz versus cryptocrystallines) measures the relative contribution of flake- and shatter- and microlithic technology in supplying that demand. Microlithic technology was clearly the preferred means of satisfying increasing lithic demand. Assemblage size is positively correlated with the cryptocrystalline fraction \( r_{\text{size-cryptocrystalline}} = 0.73 \) and negatively correlated with the quartz fraction \( r_{\text{size-quartz}} = -0.69 \). Large assemblages are cryptocrystalline-rich and quartz-poor. Given this demand, the scarcity of the fine-grained cryptocrystallines needed for microblade production becomes apparent when the cryptocrystalline fraction is plotted against assemblage size. In the 20 individual 10-cm levels with lithic samples large enough to be representative \( n \geq 15 \), the cryptocrystalline fraction increases to an asymptote, approaching but never exceeding 60\% (Fig. 1), showing that Dadiwan Phase microblade makers wanted, but could not get, more cryptocrystallines.

Figure 1. Cryptocrystalline fraction of lithic assemblages. Cryptocrystalline fraction increases asymptotically with assemblage size, reaching a maximum of approximately 60\%.

calBP (Xinglongwa, Houli, Cishan, and Peiligang). The down-side to such systems is the strong chance that climatic or demographic reversals of even modest scope will result in their extinction, which was evidently the fate of the Dadiwan Phase of the Laoguantai tradition, as well as other known early millet farming complexes. It was not, of course, the fate of the Banpo variant, which grew explosively and almost overnight into a full-blown intensive Yangshao agricultural techno-complex. The origin of the Banpo variant, its low-level agricultural form, has remained obscure despite decades of intensive research. Also, hunting remained important in Late Banpo times, even in the presence of intensive millet agriculture. These suggest points that, like the Laoguantai variant, Banpo developed among small, thinly spread groups of hunters who incorporated millet to increase their hunting success and make the change to agriculture fairly quickly without having to confront the frequency-dependent obstacles faced by larger, more stable and densely settled groups, which greatly slowed agricultural transitions in Mesoamerica and the Near East.

The Dadiwan record suggests that what makes the development of millet farming in north China different from the better-known agricultural revolutions of the Near East and Mesoamerica is its connection to hunting. This is reflected in an archeological record that is frustratingly sparse because it was the product of a rapidly evolving, game-dominated adaptation of people who were too few and too mobile to leave much evidence attesting to their experiments with millet. A growing body of evidence raises the possibility that Dadiwan-like trajectories, in which agriculture evolved among highly mobile, animal-dependent groups scantily represented in the archeological record, may well be common in much of the Old World, South Asia in particular. In any event, our knowledge of the Dadiwan record will certainly improve with additional research. We now know, for instance, that microblade technology was scaled down to counter the shortage of essential raw materials met by microlithic groups as they moved into...
the western Loess Plateau, which is
why the preagricultural microlithic
assemblage at Dadiwan was previ-
ously missed. It consists almost
entirely of very scarce and very small
stone tools that pass unseen unless
large volumes of deposit are screened
with extremely fine mesh, a labor-
tensive departure from the earlier PRC
Neolithic excavation protocol that
might well be productive if applied
to other previously excavated early agri-
cultural sites. Even with these and
other methodological refinements,
however, the archeological record of
the transition to millet agriculture will
never resemble the records of agricul-
tural revolutions elsewhere because
millet farming in north Asia evolved
along different lines: it was invented
by hunting peoples who left little of
themselves for archeologists to find.

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