LITHIC
TECHNOLOGICAL
SYSTEMS AND
EVOLUTIONARY
THEORY

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This chapter presents a very simple argument: that technology in general, and lithic technology in particular, can shed critical light on conditions surrounding and contributing to major behavioral innovations, in this case the origin of agriculture. There are probably as many views on the subject as papers, but there is a fairly clear divide between those who argue that agriculture evolves under conditions of scarcity—among them Binford (1968), Bar-Yosef (1998), Childe (1951), and others (e.g., Moore et al. 2000)—and those who argue that it evolves under conditions of plenty (Braidwood and Howe 1960; Price and Gebauer 1995:7–9). The “conditions of plenty” view is prominent in discussions of the emergence of millet agriculture in North China (Barton 2009) and specifically the argument that, in common with nearly all early experiments with food production, millet farming developed among complex, “affluent” hunter-gatherers living in large, permanent settlements in highly productive riparian and lacustrine settings that offered a rich variety of wild plants and animals (Crawford 2006:91; Smith 1995). This view portrays experiments with millet farming as solidifying a position of strength, increasing the yield and reliability of an already important staple in an already intensive and highly successful hunting-and-gathering economy (Smith 1995:136–137). Lu (2006), on the other hand, advocates the alternative “conditions of scarcity” view. Observing no archaeological evidence that China’s first farmers were sedentary and that, in contradiction to the abundance argument, agriculture arrived relatively late in the areas of greatest natural plant and animal
productivity (e.g., South China, Yangzi basin), Lu (2006:146–149) argues that sedentism and food production were both responses to declining wild resource return rates resulting from population growth leading to overharvesting and territorial circumscription.

**SCARCITY VERSUS ABUNDANCE: TEST IMPLICATIONS**

In theory, it should be easy to devise tests permitting a clear choice between these alternative evolutionary scenarios for the origins of millet farming. The diet breadth model drawn from optimal foraging theory, for example, provides formal predictions connecting subsistence choice to resource abundance (Bettinger 2009). When resources are abundant relative to demand, diet breadth should be narrow; more formally, the marginal rate of return (i.e., the cost threshold below which resources should be ignored) will be high and foragers should pursue only “high-ranked” resources, that is, resources that are relatively easy to acquire and process, producing returns greater than or equal to the marginal rate of return. As resources grow scarce, diet breadth should widen; again, more formally, the marginal rate of return drops and consumers should become less selective, adding “low-ranked” resources, which return increasingly less food value per unit of procurement and processing time. The overall state of subsistence (abundance relative to demand), then, is measured by the marginal rate of return and indexed by the handling time of the costly (i.e., lowest ranked) resource in the diet. Thus, the “conditions of plenty” argument would have agriculture evolving in concert with subsistence patterns, and consequently archaeobotanical and archaeofaunal assemblages, dominated by high ranking taxa; the “conditions of scarcity” argument would have just the reverse, assemblages dominated by low-ranking taxa.

Unfortunately, the distinction between high- and low-ranked species is not always clear, certainly not in the archaeological record. Body size may (Broughton 1999) or may not (Bird, et al. 2009) index prey rank, for example. Too, in most instances, rank is often more a function of context than species—a diseased deer sighted on the far side of a steep canyon will probably rank lower than a fat rabbit with a broken leg sighted a few yards away on this side. These and many additional complications that come readily to mind (e.g., differential butchering and preservation) prevent any simple reading of archaeological diet breadth from floral or faunal assemblages.

Although procurement technology complicates resource ranking (netted and speared salmon ranking differently, for instance), it affords more consistent and direct insights about relative resource abundance than judgments about the marginal rate of return drawn from diet breadth subsistence remains. This is because the rational tool maker will fashion all but the most expedient tools to optimize expected future returns, that is, in accord with projections about
resource conditions and some central tendency (mean, minimum, maximum, etc.) of the marginal rate of return likely to obtain over some future period, presumably the life of the tool being made. Although actuated via decisions informed by essentially the same projections, the sum total of foraging that actually occurs during this interval, and thus the archaeological residue generated, will vary stochastically in response to real resource encounters. In this sense, the diet breadth model incorporates the marginal rate of return in a form of environmental possibilism (Bettinger 1991). Diet breadth cannot predict what foraging will occur, because resource encounters are random; diet breadth merely predicts what foraging will not occur, specifically for resources with handling returns below the marginal rate of return. How closely actual foraging behavior indexes the marginal rate of return is an empirical problem, depending on sample size (number of resource encounters) and the probability of encounters with resources with handling return rates immediately above the marginal rate of return. Technology does not suffer this defect. Both foraging and tool making require judgments about resource supply and demand (i.e., the marginal rate of return), but tool design is determined by these judgments, foraging merely limited by them.

Macrofossils representing on-the-ground subsistence behavior are obviously important, but so long as demand for, and supply of, resources does not vary dramatically over the use lives of the implements employed in their procurement, technology provides a more reliable index of forager judgments about these conditions. The clearest predictions about technology in relation to these basic relationships is the simple model of technological investment developed by Bettinger et al. (2006) from the more complex version originally presented by Ugan et al. (2003). Space permits only brief explication of this model here, a more detailed treatment, complete with exercises, being presented elsewhere (Bettinger 2009).

TECHNOLOGICAL INVESTMENT

In simplest form, the technological investment model examines the replacement of alternate procurement technologies characterized by two key variables:

- $m_i$: manufacturing time—time spent making a particular kind of procurement technology $i$, expressed here in hours (hr)
- $r_i$: procurement rate—the rate at which a resource is obtained using technology $i$, expressed here in kilocalories per hour (kcal/hr)

In Figure 6.1, for example, technology 1 and 2 are characterized by their manufacturing times $m_1$ and $m_2$, by the rate at which kilocalories are procured using them $r_1$ and $r_2$, and by the relationship of these variables $r_1 / m_1$ and $r_2 / m_2$, the rate at which manufacturing time increases rate of procurement, that
6.1. Relationship between two technologies characterized by manufacturing times \(m_1\) and \(m_2\), by the rate at which kilocalories are procured using them \(r_1\) and \(r_2\), and by the relationship of these variables \(r_1/m_1\) and \(r_2/m_2\).

is, investing in \(m_1\) produces a return rate of \(r_1\) and investing in \(m_2\) produces a return rate of \(r_2\). Here technological evolution is treated as a competition between technologies characterized by different combinations of \(r_n, m_n\), and \(r_i/m_i\). In the simplest case there are two alternatives. For either to be competitive in the presence of the other, it must satisfy one of two conditions.

1. The more costly technology must produce a higher rate of return. Formally, if \(m_2 > m_1\), then \(r_2 > r_1\).

2. The lower return technology must produce a rate of return per unit of manufacturing time that is at least equal to that of the technology with the higher return. Lower returns can be justified only by costs low enough to make the lower return technology at least equivalent to its higher return alternative in terms of rate of return per unit of manufacturing time. Formally, if \(r_1 < r_2\), then \(r_1/m_1 \geq r_2/m_2\).

Meeting both these conditions, the alternative technologies 1 and 2 depicted in Figure 6.1 are mutually viable; the more costly technology produces a higher rate of return \((r_2 > r_1)\); and the lower return technology a greater rate of return per unit of manufacturing time \((r_1/m_1 > r_2/m_2)\).

With only these variables (manufacturing time and return rate) in play, of course, it will never pay to invest in the more costly technology 2; technology 1 is superior in all respects, both cheaper \((m_1 < m_2)\) and producing a better
6.2. Relationship between two mutually viable technologies. The more costly technology 2 produces a higher rate of return \( (m_2 > m_1 \text{ and } r_2 > r_1) \) and the less productive technology 1 produces a higher rate of return per unit of manufacturing time \( (r_1 > r_2 \text{ and } m_1 > m_2) \), making technology 1 superior when procurement time is less than \( s_{1\rightarrow 2} \) and technology 2 superior when procurement time is greater than \( s_{1\rightarrow 2} \).

payoff per unit of manufacturing time \( (r_i/m_i > r_j/m_j) \). The more costly technology 2 may make sense, however, if procurement returns are measured not just in relation to time spent making tools but in relation to time spent making and using tools, in this case, the sum of manufacturing time \( m \) and procurement time \( s \), formally defined as

\[ s = \text{the total amount of time expended in procurement of a resource, again expressed in hours (hr)}.\]

When procurement time \( s \) is included, the object is to maximize return rate \( r_i \) relative to the sum of manufacturing time and procurement time, that is, maximize \( r_i / (m_i + s) \) rather than \( r_i / m_i \). Thus even when \( r_i/m_i > r_j/m_j \), because \( r_j > r_i \) if \( s \) is large enough \( r_j / (m_j + s) > r_i / (m_i + s) \). This is shown by the solid line in Figure 6.2, where the return rate of technology 1 and 2 are just equal at \( s_{1\rightarrow 2} \), which is the procurement time switching point between the cheaper technology 1 and more costly technology 2. When procurement time is greater than \( s_{1\rightarrow 2} \), the costlier technology produces a higher rate of return. When it is less than \( s_{1\rightarrow 2} \), the cheaper technology produces a higher rate of return.

In addition to the kind of replacement discussed in the preceding text, technological intensification can also take the form of refinement, reflected in increasingly more effective and costly versions of a basic design, for example, fishhooks. As when two qualitatively distinct technologies are involved (e.g., nets vs. hooks), refinement increases procurement returns at a decreasing rate, in this case, however, as a continuous function, increasing procurement
6.3. Relationship between manufacturing time and return rate as a single technology is increasingly refined, increased manufacturing cost producing higher returns at a steadily decreasing rate. Incremental increases in procurement time warrant incremental technological refinement.

time warranting increasingly more productive but costly refinements. Critical procurement time – the procurement time required to warrant a particular degree of refinement – is given by the x-axis intersection of tangents to the curve describing change in procurement rate as a function of manufacturing time (Figure 6.3). Refinement of the technology depicted in Figure 6.3 will begin when procurement time reaches \( s_1 \); and proceed continuously with increasing procurement time. The point labeled \( 1 \) represents the technology in unrefined form, the point labeled \( 4 \) its most refined form, and points \( 2 \) and \( 3 \) intermediate degrees of refinement warranted when procurement time reaches exactly \( s_2 \) and \( s_3 \) respectively.

Whether dealing with two qualitatively distinct but mutually viable technologies or differentially refined versions of a single technology, the choice between less expensive and more costly alternatives hinges on the marginal rate of subsistence return (the rate at which resources are acquired relative to procurement and manufacturing time) and changes as a function of procurement time (manufacturing time being fixed). If resources are abundant (i.e., the marginal rate of return is high), time spent in procurement will be low, and the less expensive technology superior. If resources are scarce (the marginal return rate is low), time spent in procurement will be high, and the more costly technology superior. For this reason, the cost of the most expensive technology in use at a given time will vary inversely with the overall rate of subsistence return, that is, resource abundance relative to demand. Further, among groups fielding the same suite of technologies in roughly the same environments for
roughly the same purposes, those under the greatest resource stress as measured by resource supply relative to demand, will display the most costly refinements of the most costly technology.

Early millet farming is particularly well suited to this sort of analysis because traditional wisdom has it evolving from a well-defined techno-complex (Clark 1968) – the intensive late Pleistocene hunter-gatherer adaptation termed here the *North China Microlithic*, whose hallmark microblade technology was certainly among its most costly, requiring more skill and higher quality raw materials than any earlier North Asian stone tool technology. The archaeological record of this microblade-using hunter-gatherer to millet-growing farmer connection is poorly documented, however, and as a result the early agricultural revolution in north China is not as well understood as those that have occurred in other parts of the world.

**ORIGINS OF MILLET FARMING IN NORTH CHINA**

Early millet farming is represented in at least five geographically separate but roughly contemporaneous cultural complexes (Laoguantai, Peligang, Cishan, Houli, and Xinglongwa) distributed over an environmentally diverse area stretching 1500 km from the northeast China Plain to the western Loess Plateau (Figure 6.4). The published literature, however, 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. Among the many possible scenarios, the traditional view that millet farming evolved from the North China Microlithic (Barnes 1993; Bettinger et al. 2007; Elston et al. 1997; Lu 1998, 1999, 2006; Madsen et al. 1996) is certainly the most plausible yet highly problematic because the hallmark microblades and microblade cores common in North China Microlithic sites (e.g., Xiachuan, Xueguan, Shizitan, Shayuan, Hutouliang) are rare or absent in nearby early millet farming sites (e.g., Cishan and Peligang). Indeed, Dadiwan lies well outside of the main distribution of the North China Microlithic (Gai 1985), the nearest representatives of which are directly north on the upper Yellow River and adjacent deserts. In any event, prior to the data presented here not one stratified assemblage or series of related assemblages had bridged this technological gulf from microblade-using forager to millet-raising farmer. As we show in this chapter, this disconnect is not an artifact of archaeological bias, preservation, or sampling. Rather, it is the signature of an agricultural transition authored by hunter-gatherer systems operating at the very edge of their natural range, using a microlithic technology at the very edge of its natural range, the combination defining what was quite clearly a marginal environment. To support this argument, we report recent work at the Dadiwan site, which provides the
first complete archaeological sequence from north China to record behavioral variation across the transition to agriculture.

DADIWAN

The Dadiwan site (105.904°E, 35.015°N) in Shao Dian Village, Qin'an County, Gansu Province, P.R.C., is the oldest known example of the Dadiwan (or Laoguantai) cultural complex, which is the westernmost expression of early millet agriculture in North China (Figure 6.4). The original excavations (1978–1984) revealed a multistage cultural sequence beginning with a Dadiwan phase (7900–7200 BP) occupation representing primitive or low-level millet farming (Gansu 2003, 2006). As with all early millet-based agricultural sites in North China, no evidence of a preagricultural hunting and gathering occupation was found. However, surveys near the Dadiwan site in 2002 recorded a late Pleistocene archaeological culture we have called “Zhuang Lang-Tong Xin” (32,000–18,000 cal BP) (Barton et al. 2007; Betteny et al. 2005), and test excavations in 2004 hinted that this Zhuang Lang-Tong Xin assemblage and a microblade technology related to the preagricultural North China Microlithic were both present at Dadiwan itself. Work in 2006 and 2009 confirmed the presence of, and demonstrated the stratigraphic and developmental relationship between, these complexes and the earliest farming phase at Dadiwan.

Although Dadiwan’s status as a protected national landmark limited the scope of our work, we excavated to a depth of 10 m, removing 29.14 m³ of deposit in 10 cm arbitrary levels, screening 23.2 m³ of that through 3.0 mm
mesh. With the exception of single flake found in situ between 9.6 and 9.8 m, the cultural assemblage is confined to the upper 7.1 m of deposit, artifact distributions justifying division of the dividing the relatively undisturbed lower 6.6 m of that into six components (Figure 6.5; Table 6.1).

Almost all sherds (98%) recovered in the undisturbed deposit were from the top two components (5–6), which match ceramic occupations recognized in previous excavations: early incipient Dadiwan farmers (Component 5) and later intensive Late Banpo farmers (Component 6). The preceramic Components 1, 2, 3, and 4 were separated on the basis of lithic technology described in brief in the next section.

LITHIC TECHNOLOGY

There are few formal or retouched tools among the 1165 pieces of chipped stone. The dominant technology, which we call flake-and-shatter, includes simple flake tools, angular shatter blocks, and core fragments produced by direct and bipolar, hard-hammer percussion, predominantly on locally abundant massive quartz river cobbles (Figure 6.6), this material accounting for 95 percent of this assemblage. This is the same percussion quartz technology that defines the late Pleistocene Zhubeng Lang-Tong Xin complex previously documented for the western Loess Plateau (Barton et al. 2007; Ji et al. 2003). Our Dadiwan data show that this technology is much older and persisted much later than we previously thought, beginning by at least 60,000 (and possibly 80,000) years and lasting until after 7000 BP. Flake-and-shatter quartz technology dominates, indeed makes up the entirety of, the assemblages from Components 1 and 2, and almost all of what little there is of Component 3, during which Dadiwan appears to have been largely abandoned — probably in response to climatic deterioration during the Last Glacial Maximum (LGM).

Tiny microblades (Figure 6.7) and microblade cores (Figure 6.8) predominantly (98 percent) fashioned from small pieces of nontypical cryptocrystallines (e.g., chalcedony) identify a second, very different lithic technology that is obviously derived from the North China Microlithic. The microblade cores are predominantly “boat-shaped” or “pebble” type (Chen 1984; Elston and Brantingham 2002) noted elsewhere in northern China, are triangular in cross section, and vary in taper to take maximum advantage of raw material. The microblades at Dadiwan are correspondingly small, and although 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 a dozen microblades, all larger, of different materials, and from post-Laoguantai components. It did, however, yield several thin, tabular bone handles with lateral margins finely slotted to accept very small microblade insets of the scale we recovered (Gansu 2006). While concentrated in
6.5. Stratigraphic distribution of major Dadiwan technologies by density per cubic meter.
TABLE 6.1. Dadiwan site components

<table>
<thead>
<tr>
<th>Component</th>
<th>Cultural complex</th>
<th>cal BP</th>
<th>Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Late Banpo</td>
<td>5700–7000</td>
<td>0.9–0.5</td>
</tr>
<tr>
<td>5</td>
<td>Dadiwan (Laoguantai)</td>
<td>7000–13,000</td>
<td>1.9–0.9</td>
</tr>
<tr>
<td>4</td>
<td>Preceramic Microlithic</td>
<td>13,000–20,000</td>
<td>2.7–1.9</td>
</tr>
<tr>
<td>3</td>
<td>LGM (abandoned?)</td>
<td>20,000–33,000</td>
<td>2.7–3.9</td>
</tr>
<tr>
<td>2</td>
<td>Zhuang Lang-Tong Xin</td>
<td>33,000–42,000</td>
<td>5.1–3.9</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>42,000–60,000</td>
<td>7.1–5.1</td>
</tr>
<tr>
<td>0</td>
<td>?</td>
<td>60,000–80,000</td>
<td>9.9–7.1</td>
</tr>
</tbody>
</table>

6.6. Flake-and-shatter quartz technology, showing all specimens recovered from a single 10 cm level (160 to 170 cm) in a 2.0 m² unit (DDW03).

the early millet farming Dadiwan (or Laoguantai) Component 5 (Figure 6.7), this microlithic technology is clearly earlier than that, its presence in situ in Component 4 documenting a post-LGM, preceramic occupation quite clearly connected to the North China Microlithic (Gai 1985).
In agreement with our extensive surface surveys and conversations with local farmers that failed to locate any sources, several lines of evidence establish that the fine-grained cryptocrystalline essential to microlithic technology were scarce or entirely absent in the western Loess Plateau, suggesting the technology itself is exotic. Were cryptocrystalline at all locally abundant, for example, one would expect evidence of at least their casual use of off and on throughout the occupation of the site. Instead, they are essentially absent prior to the appearance of microblade technology. Of course, the most obvious evidence for this raw material scarcity is the miniaturization of Dadiwan’s microblade technology: cores were saved and used well beyond the normal point of discard. The 54 microblades and 10 microblade cores in our Dadiwan samples are among the smallest on record anywhere in the world. With the 27 complete specimens averaging just 9.13 mm in length (std. dev. = 1.56 mm), 3.64 mm in width (std = 0.55 mm), and 0.94 mm in thickness (std = 0.34 mm), these microblades are only two-thirds the size of microblades found in North China Microlithic sites on the upper Yellow River (Elston and Brantingham 2002), and less than half the size of those from the North American Arctic and Subarctic (Anderson 1970; Coupland 1996; McGee 1970; Sanger 1968).
6.8. Microblade cores showing all specimens recovered from site. Top row left: black chalcedony, 100–110 cm; top row right: white chalcedony, 120–130 cm; second row left: black chalcedony, 140–150 cm; second row right: black chalcedony, 140–150 cm; third row left: white chalcedony, 160–170 cm; third row right: white chalcedony, 200–210 cm; bottom row left: white chalcedony, 200–210 cm; bottom row right: quartz, 220–230 cm.

Similarly, the nine complete microblade cores average just 10.18 mm from height (platform to base), 10.34 mm in width (side to side), and 18.40 mm in length (front to back), less than half the size of the smallest Neolithic specimens reported from deserts to the north (Chen 1984) and from the North American Arctic and Subarctic (Sanger 1968). Diminutive to begin with, this technology seems to have become ever smaller through time – at least as measured by microblade core height, which diminishes as one moves higher in
the deposit (Figure 6.9). Its size justifies the term suggested to us by our
colleague Richard Klein, *nanolithic*, referring to a formal prismatic core technol-
ogy scaled to produce blades with a mean length of less than 1 cm, an order of
magnitute smaller than the upper limit for microblade length (10 cm).

An alternate perspective on this raw material scarcity is provided by the relation-
ship between the size and raw material composition of lithic assemblages.
Here assemblage size can be thought of as a proxy for stone tool demand.
Further, because microlithic technology is 98 percent cryptocrystallines, flake-
and-shatter technology 95 percent quartz, the material composition of lithic
assemblages (i.e., cryptocrystalline fraction) measures the relative contribu-
tion of microlithic and flake-and-shatter technology in supplying stone tool
demand. Microlithic technology was clearly the preferred means of satisfy-
ing increasing lithic demand; assemblage size is positively correlated with the
cryptocrystalline fraction ($r_{\text{size-cryptocrystalline%}} = 0.70$) and negatively correlated
with the quartz fraction ($r_{\text{size-quartz%}} = -0.66$); large assemblages are richer in
cryptocrystallines and poorer in quartz. Given this, the scarcity of the fine-
grained cryptocrystallines needed for microblade production becomes appar-
ent when the cryptocrystalline fraction is plotted against assemblage size. In
the 57 samples representing an individual 10 cm level with lithics present, the
cryptocrystalline fraction increases to an asymptote, approaching but never
exceeding 60 percent (Figure 6.10). Obviously, Dadiwan’s knappers wanted,
but had trouble getting, more cryptocrystallines, a proposition that matches
predictions about technological intensification via refinement. Like the cur-
vilinear function depicted in Figure 6.3, the size-composition relationship in
Figure 6.10 tracks technological refinement, lithic technology progressively
6.10. Relationships between size and cryptocrystalline fraction of lithic assemblages.

shifting from the less costly flake-and-shatter to the more costly microblade technology in keeping with increasing stone tool demand, that is, use time. That the cost of microblade use was very high from the very start is indicated by the miniaturization of this technology. The asymptote of 60 percent simply represents the point at which the costs of further reliance on microblade technology were no longer justified at existing levels of demand.

DISCUSSION

That microblade technology appeared so abruptly at Dadiwan (Figure 6.5), outside the main distribution of the North China Microlithic in a region lacking the fine-grained raw material essential for its production, makes it an almost foregone conclusion it was an exotic import, representing an influx of North China Microlithic populations from the north, where the technology and necessary raw materials are common. That this microblade technology appears before, but becomes most prominent during, the Laoguantai Phase 7000–13,000 BP further implies that these migrants (not long-term locals) were responsible for the development of Dadiwan's millet agriculture. Whatever the function of these diminutive microlithics (use in clothing manufacture seems most likely; Yi et al. 2013), they were clearly considered important enough to justify major expenditures of time and effort in acquiring the raw material and substantial sacrifices in functional efficiency as the technology
was scaled down to suit raw material shortages. Dadiwan’s microblade technology was clearly more costly than versions found further north in the heart of the North China Microlithic, making it the most costly form of the most costly lithic technology in post-LGM North China. This makes it plain that at least at Dadiwan, millet agriculture evolved in what was quite clearly a marginal environment, if not in terms of subsistence resources then certainly in the availability of the raw materials required for everyday life.

REFERENCES


