12

Using Cladistics to Construct Lineages of Projectile Points from Northeastern Missouri

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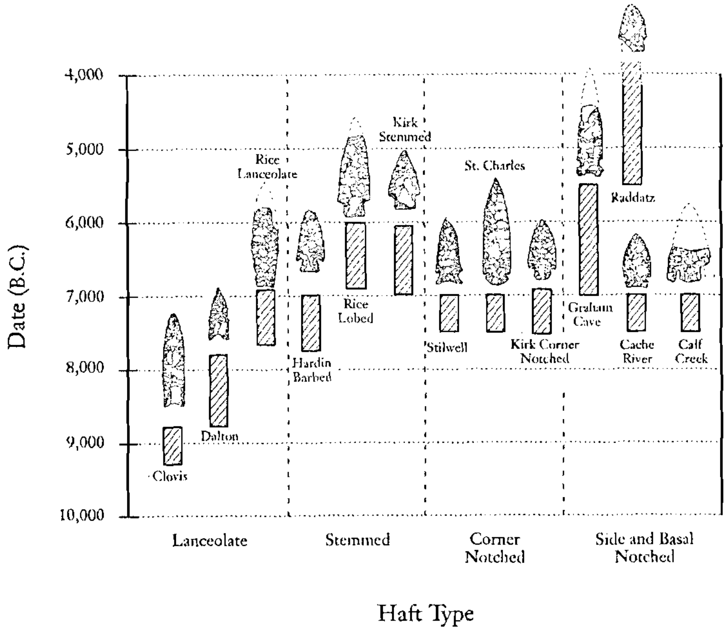
The evolution of projectile points in the late Paleoindian and Early Archaic periods (ca. 8950–6000 B.C. uncalibrated radiocarbon years) in what is now northeastern Missouri (United States) was marked by a series of changes that first saw a radiation in diversity followed by a narrowing of variation (figure 12.1). The sequence began around 9250 B.C. with lanceolate Clovis points, which likely gave rise to Dalton points around 8850 B.C. (Bradley 1997; O'Brien et al. 2001; O'Brien and Wood 1998). Sometime thereafter, certainly by 7900 B.C., the radiation in point form began. Starting with the appearance of stems, every form of haft known from prehistoric Missouri, including side, corner, and basal notches, developed by 7500 B.C. Lanceolate points apparently were still being manufactured alongside these new forms (O'Brien and Wood 1998). This mosaic of point forms continued until 7000 B.C., when most hafting technologies began to disappear. With the exception of some stemmed forms, most projectile points made over the next 4,000 years were side notched. To understand why side-notched points came to ascendancy, we need to determine the sequence of changes that led to their development and that of other point forms of the period.

Here we present one portion of a much larger study in the use of cladistics to reconstruct the phylogeny of early projectile points in northeastern Missouri. We use cladistics because of its unique ability not only to create testable lineages of points but also to lay out sequences of character-state changes (O'Brien and Lyman 2002a, 2003a, 2003b; O'Brien et al. 2001, 2002). Thus, we can track the historical developments that eventually led to the appearance of side-notched points. The ultimate goal of this procedure is to explain why side notching was preferred over other hafting techniques.

Figure 12.1
Temporal Ranges of Specific Projectile-Point Types Found in Northeastern Missouri



All ranges were assigned based on O'Brien and Wood's (1998) review of Paleoindian and Early Archaic–period projectile points in Missouri, with the exception of those for Kirk Corner Notched and Kirk Stemmed, which were drawn from Justice (1987).

Cladistics and the Archaeological Record

Cladistics is a method that "in its purest form, seeks to group taxa into sets and subsets based on the most parsimonious distribution of characters" (Forey 1990: 430). The underlying requirements for using cladistics to infer phylogenetic relationships for a set of phenomena are that the phenomena must evolve through decent with modification and be hierarchically related (Davis and Nixon 1992). Obviously, biological organisms fall within these parameters, but it has also been demonstrated that cladistics is applicable to the study of manuscripts and language (e.g., Platnick and Cameron 1977; Ross 1997) as well as other cultural and biocultural phenomena (e.g., Holden and Mace 1997, 1999; Mace and Pagel 1994; Sellen and Mace 1997), including those occurring in the archaeological record (Collard and Shennan 2000; Foley 1987; Jordan and Shennan 2003; O'Brien and Lyman 2000a, 2002, 2003a, 2003b; O'Brien et al. 2001, 2002; Tehrani and Collard 2002; chapter 13, this volume). We do not review this work, taking it for granted that there are no insurmountable theoretical or methodological obstacles to using cladistics to create artifact phylogenies (chapter 1, this volume). We also take for granted that the reader is familiar with the basics of cladistics.

Cladistic hypotheses are created without using temporal or spatial information, which makes them independent hypotheses concerning form alone. Consequently, they can be tested against time—the fossil/archaeological record—because there is an ordinal-scale sequence to the taxa on a phylogenetic tree that can be compared to the order in which the taxa arose in the fossil record—assuming that the history of life is reflected in the sequence of fossils (Benton 1995). When working with cultural phenomena, we assume that the history of cultural change is reflected in the sequence of artifacts in the archaeological record (chapter 6, this volume).

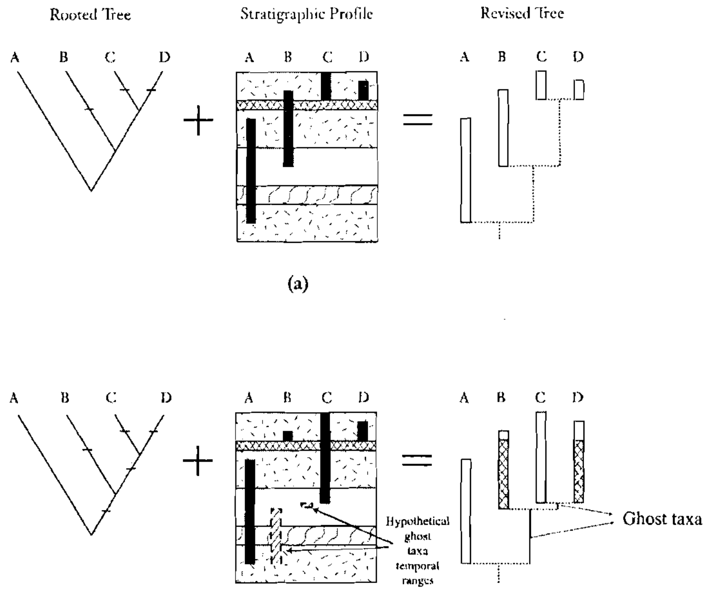
In order to examine trees in terms of the fossil record, they must be converted into trees where time is added. This is done by placing the terminal nodes of a tree at the point of earliest occurrence of fossil taxa (figure 12.2). In situations where there is complete congruence between the tree and the fossil record, a tree can be placed on the existing known temporal ranges of the taxa (figure 12.2a). However, in situations where a node of the tree must be lowered beyond the temporal range indicated in the known chronological sequence, the open space between the node and the taxa range is filled in with an extended, or "ghost," range in order to maintain a logical order based on derived characteristics (figure 12.2b).

Likewise, when the tree indicates a character developed before the divergence of two taxa, which results in it not being on a terminal branch of the tree, a "ghost taxon" is used to connect the nodes (Norell 1992, 1993) (figure 12.3). Just as with any other taxon, a ghost taxon has all the formal properties of a regular taxon; however, its range is determined by the sequence of the tree.

In simplest terms, the phylogenetic tree that needs the fewest ghost-range extensions in order to keep logical consistency is the best phylogenetic reconstruction. One way to assess this for a group of trees is to compare the number of range extensions that are needed to fit each tree to the fossil record. The tree requiring the fewest extensions is the best representation of the phylogeny, assuming that the fossil record is accurate (Benton 1995). In the example illustrated in figure 12.3, tree (a) fits better with the fossil record than tree (b) does because tree (a) requires only one range extension as opposed to the three needed by tree (b). Similarly, if we add the number of temporal intervals required for range extensions, tree (a) is again superior, as it requires two as opposed to thirteen intervals of range extension.

After a phylogenetic tree is calibrated to the fossil/archaeological record, it is possible to explore the temporal nature of each character change. At any time around a speciation event, there potentially could be taxa that have some, none, or different characters than the taxon that eventually arose. How-

Figure 12.2
Two Different Scenarios for Converting a Cladogram into a Calibrated Phylogenetic Tree



(a)

(b)

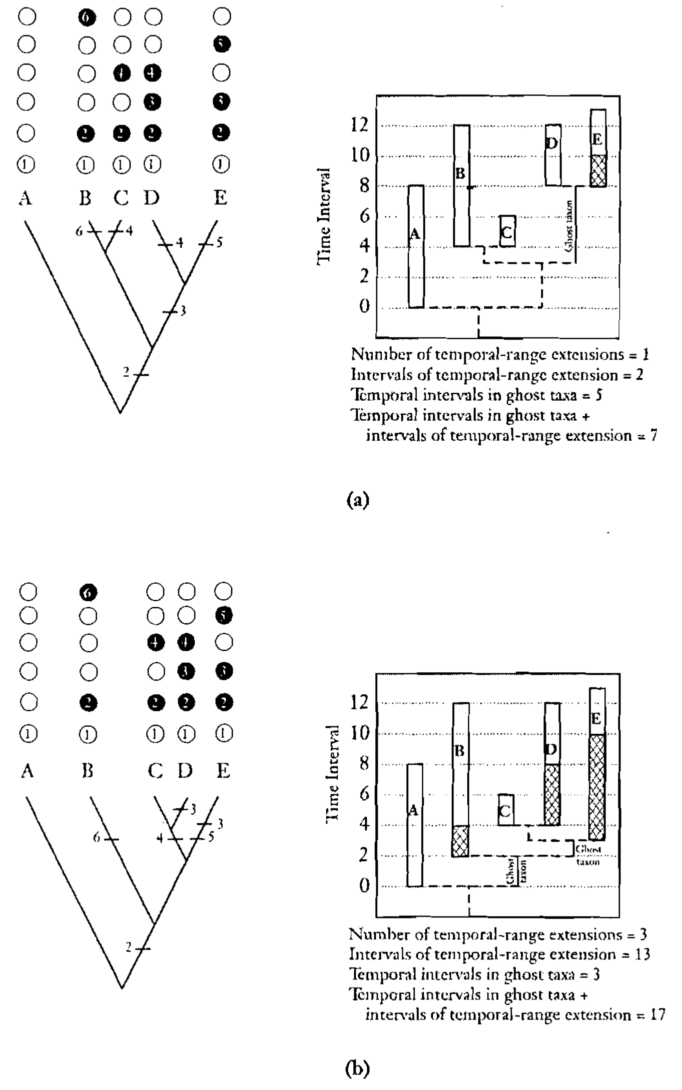
On the rooted cladograms, the positions of character changes are noted by horizontal lines on branches. The temporal range of each taxon is indicated in the stratigraphic profile by solid bars and on the phylogenetic tree by open bars. In (a), the nodes of the cladogram are simply mapped onto the existing stratigraphic ranges for the taxa because there is complete congruence between the position of the taxa on the cladogram and their occurrence in the stratigraphic profile. In (b), the ranges of taxa B and D need to be extended in order to keep the logical order of the cladogram intact, which are indicated by cross-hatched bars. Taxon B must come before Taxon C in temporal range because it comes before Taxon C on the cladogram. Taxa C and D are sister taxa because they depart from the same node; therefore, Taxon D's range must be extended back to the same time that Taxon C originated. Also depicted in this example are two ghost taxa and their predicted ranges in the stratigraphic profile, which are set by their position on the phylogenetic tree (Norell 1992, 1993).

ever, with the temporal information it is possible to begin to assess the rates of change within each character. On an individual level, it is possible to see which characters are relatively stable over time versus those that change rapidly or to see if some go through bursts of activity or are under constant change. On a group level, it is possible to discern periods when there is rapid change occurring in a number of characters versus times of relative stability.

It also is feasible to begin to formulate models concerning the nature of the origin of each character. For derived characters the simplest explanation is that

Figure 12.3

Comparison of Two Alternate, though Equivalent in Terms of Tree Length, Phylogenetic Hypotheses for the Same Character Matrix Using the Fossil Record



Number of temporal-range extensions = 1
Intervals of temporal-range extension = 2
Temporal intervals in ghost taxa = 5
Temporal intervals in ghost taxa + intervals of temporal-range extension = 7

Number of temporal-range extensions = 3
Intervals of temporal-range extension = 13
Temporal intervals in ghost taxa = 3
Temporal intervals in ghost taxa + intervals of temporal-range extension = 17

On the left are two rooted cladograms with the data matrix specified in the overhead circles (derived characters in filled circles) and the position of each change indicated on the branches. On the right are two phylogenetic trees, with the open bars indicating taxa ranges and the cross-hatched bars depicting temporal range extensions. Tree (a) is a superior hypothesis of the phylogeny because it requires less temporal range extensions and total number of increments of range extension than tree (b) does.

they are part of a line of heritable continuity. However, characters that are the result of homoplasy in archaeological phenomena can be the result of independent invention in a line of heritable continuity or of horizontal transmission (Mace and Pagel 1994). With a phylogenetic tree it is possible to speculate as to which form of transmission was related to the character change. Similar character changes that occur temporally (and spatially) closer to each other are more likely to be the result of horizontal transmission than those that are not. For example, if certain identical character changes appear simultaneously across several lineages, it might signify that the traits are the result of horizontal transmission. However, if such traits appear in staggered order through time, each change is more likely to have been the result of independent invention. Unfortunately, there is no method to prove whether a similar character change in two lineages at roughly the same time is the product of horizontal transmission. Even with the addition of spatial evidence into such speculations, all such conclusions are circumstantial because past cultural transmission cannot be observed.

Methods and Materials

A paradigmatic classification based on thirteen characters was used to classify projectile points, with most of the characters relating to the hafting area (see figure 12.4 for measurement locations and table 12.1 for characters and states). We believe the haft is the most likely area to exhibit the effects of transmission (Beck 1995, 1998) and thus is likely to carry a strong phylogenetic signal (O'Brien et al. 2001). We used fairly small-scale characters and character states. For example, instead of having one character that broadly categorizes a haft as being side, corner, or basal notched, or as contracting, straight, or expanding stemmed, we have four characters that together monitor the lower shoulder angle/upper notch angle, the notch shape, the notch depth, and the lower notch angle. By taking this approach, we attempted to make our characters as independent as possible.

We selected twenty-one classes of points that included five corner-notched, four lanceolate, four side-notched, and seven stemmed specimens, as well as one basal-notched point (figure 12.5; table 12.2). When choosing these classes, we tried to include as many specimens as possible from Zone III of the Pigeon Roost Creek site—the most thoroughly studied stratified archaeological site in northeastern Missouri (O'Brien and Warren 1983). Most of the projectile points recovered from this zone fell into established point types associated with either the late Paleoindian period or the Early Archaic period (table 12.2) and were below Middle Archaic–period points and radiocarbon dates (O'Brien and Wood 1998).

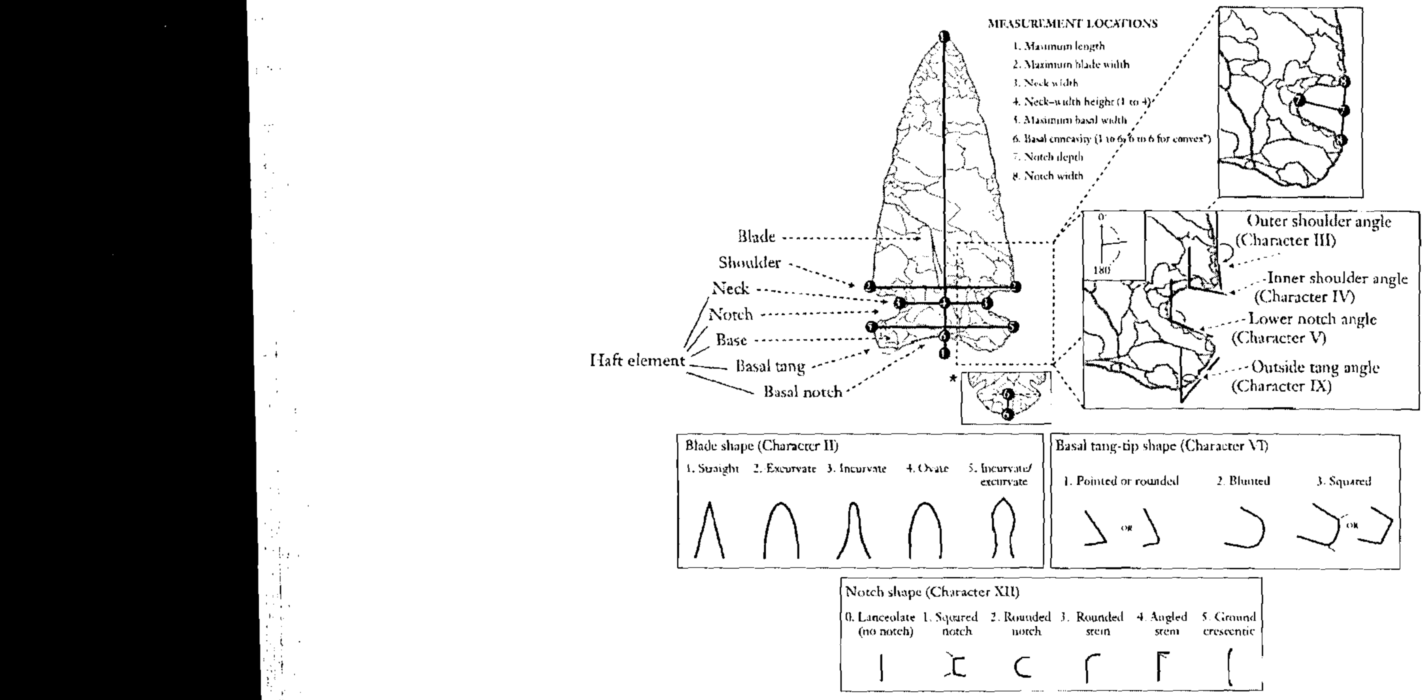
We selected a Clovis point from the Kimmswick site in Jefferson County, Missouri, to serve as the outgroup (table 12.2). This choice was made because Clovis points likely preceded all others in the region, and there is technological evidence that suggests that Dalton points evolved out of Clovis points

Table 12.1
Definitions of Characters and States for Projectile-Point Classification

Character	Definition	State
I	Length-to-width ratio	1. < 1.4 2. 1.5–2.9 3. > 3.0
II	Blade shape	1. Straight 2. Excurvate 3. Incurvate 4. Ovate 5. Incurvate/excurvate
III	Outer shoulder angle	0. No shoulder present 1. 1–30° 2. 31–60° 3. 61–90° 4. 91–120° 5. 121–150° 6. 151–180°
IV	Inner shoulder angle	0. No shoulder present 1. 1–45° 2. 46–90° 3. 91–135° 4. 136–180°
V	Lower notch angle	0. No notch present 1. 136–180° 2. 90–135° 3. 46 89° 4. 1–45°
VI	Basal tang-tip shape	1. Pointed or rounded 2. Blunted 3. Squared
VII	Neck-constriction–height ratio (neck height/length)	1. < 0.1 2. 0.1–0.19 3. > 0.19
VIII	Basal-concavity ratio	1. < 0.8 2. 0.8–0.99 3. 1.0 4. > 1.0
IX	Blade-to-base ratio (blade width/base width)	1. < 0.9 2. 1.0 3. 1.1–1.9 4. 2.0–4.0 5. > 4.0
X	Notch-depth ratio (notch depth/notch width)	0. No notches 2. 0.01–0.5 3. 0.51–1.0 4. > 1.0
XI	Outside tang angle	0. No outer tang/tang shape pointed or rounded 1. 0° 2. 1–45° 3. 46–89° 4. 90–135° 5. 136–179°
XII	Notch shape	0. No notches present (lanceolate) 1. Squared interior; lower margin length < 2x upper margin length (notch) 2. Rounded interior; lower margin length < 2x upper margin length (notch) 3. Rounded interior; lower margin length > 2x upper margin length (stem) 4. Angled interior; lower margin length > 2x upper margin length (stem) 5. Ground crescent-shaped notches
XIII	Neck-width-to-blade constriction ratio (neck width/blade width)	1. 1.0–0.80 2. 0.79–0.60 3. < 0.60

Figure 12.4

Illustration of the Measurements Taken on Projectile Points, along with Morphological Features of Projectile Points Used in the Text



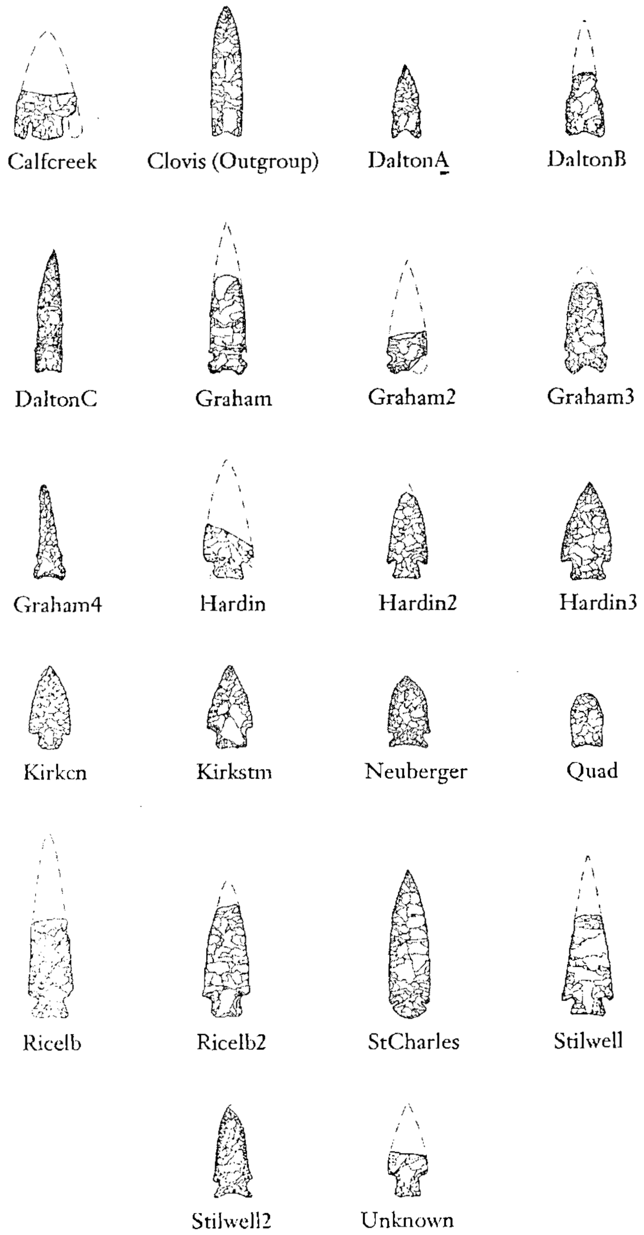
These measurements are used to calculate the character states listed in table 12.1. The two cut-away boxes on the right illustrate measurements and angles for notches and other features. All angle measurements were made between 0 degrees and 180 degrees, with 0 degrees always directed toward the tip, parallel to the long axis of the point. The lower three boxes illustrate various shapes of blades, basal tang tips, and notches.

(Bradley 1997; O'Brien et al. 2001; O'Brien and Wood 1998). Although these criteria are not hard and fast requirements for outgroup selection (Nixon and Carpenter 1993), using a point class that appears to have a direct ancestral relationship with the twenty-one ingroup taxa can be expected to enhance the phylogenetic reconstruction.

Results

Using the branch-and-bound algorithm of the phylogenetics program PAUP* (Swofford 2002), four equally most parsimonious trees were generated for the twenty-two taxa, each having seventy-two steps, a consistency index of 0.49, and a retention index of 0.66 (figures 12.6 and 12.7). Note that the two trees shown in each figure are identical except for the placement of two taxa—

Figure 12.5
Illustration of Specimens in Each of the 22 Classes Included in the Cladistic Analysis



Each specimen is at 22.5 percent of original size.

Table 12.2
Classes with Assigned Point Types, Temporal Ranges, and Provenience

Class name	Code	Point type assigned	Temporal range	Provenience [a]
Calfcreek	2264112444023	Calf Creek	7,500–7,000 B.C.	Pigeon Roost Creek, Zone III (300–310 cm B.S.)
Clovis (outgroup)	3400011230001	Clovis	9,250–8,950 B.C.	Kimmswick, Jefferson County, Missouri
DaltonA	2341123212351	Dalton	8,500–7,900 B.C.	Pigeon Roost Creek, Zone III (310–320 cm B.S.)
DaltonB	2360023210301	Dalton	8,500–7,900 B.C.	Pigeon Roost Creek, Zone III (320–330 cm B.S.)
DaltonC	3361111232051	Dalton	8,500–7,900 B.C.	Hendricks
Graham	3562232213212	Graham Cave	7,000–5,500 B.C.	Collins
Graham2	2262232212211	Graham Cave	7,000–5,500 B.C.	Pigeon Roost Creek, Zone III (320–330 cm B.S.)
Graham3	2262233212221	Graham Cave	7,000–5,500 B.C.	Cooper
Graham4	3351232212521	Graham Cave	7,000–5,500 B.C.	Pigeon Roost Creek, Zone III (300–310 cm B.S.)
Hardin	2413122233333	Hardin Barbed	7,800–7,000 B.C.	Pigeon Roost Creek, Zone III (320–330 cm B.S.)
Hardin2	2413112233043	Hardin Barbed	7,800–7,000 B.C.	Cooper
Hardin3	2213112232033	Hardin Barbed	7,800–7,000 B.C.	Collins
Kirkcn	2413132433223	Kirk Corner Notched	7,500–6,900 B.C.	Pigeon Roost Creek, Zone III (320–330 cm B.S.)
Kirkstm	2262122232232	Kirk Stemmed	6,900–6000 B.C.	Pigeon Roost Creek, Zone III (290–300 cm B.S.)
Neuberger	2563122233212	Neuberger	~7,500–7,000 B.C.	Collins
Quad	2400023230501	Quad (-like)	Late Paleoindian Period	Hendricks
Ricelb	3162122233233	Rice Lobed	6,900–6,000 B.C.	Collins
Ricelb2	3562132232233	Rice Lobed	6,900–6,000 B.C.	23MN802
StCharles	3413212434023	St. Charles	7,500–7,000 B.C.	23MN898
Stilwell	2563232233312	Stilwell	7,500–7,000 B.C.	Ross
Stilwell2	2554122233213	Stilwell	7,500–7,000 B.C.	Collins
Unknown	2262113432033	Unknown	Early Archaic Period	Pigeon Roost Creek, Zone III (290–300 cm B.S.)

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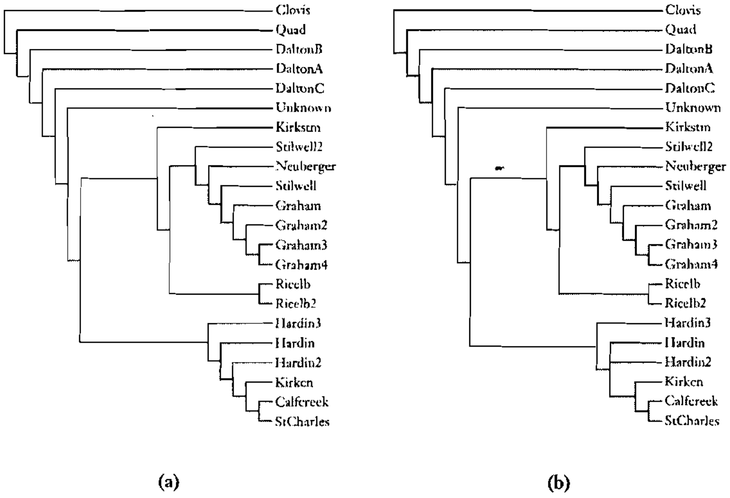
[a] All provenience information from O'Brien (1985) except for Kimmswick (Graham et al. 1981); B.S. = below surface.

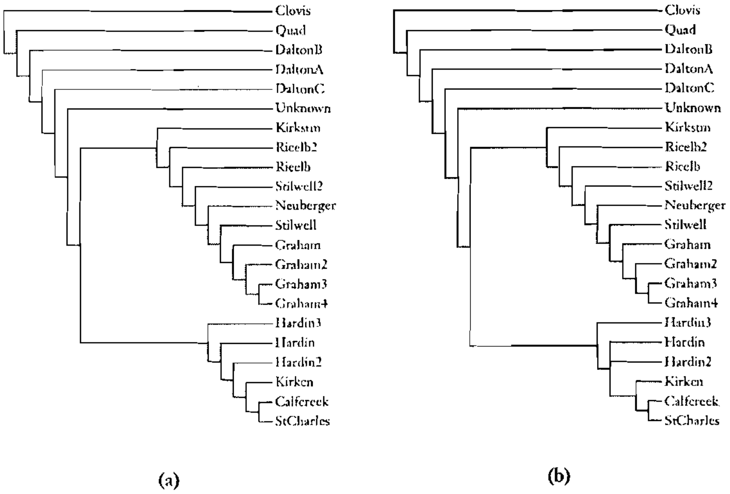
Figure 12.6
Two of Four Equally Parsimonious Rooted Cladograms for the 22 Taxa Included in the Analysis



(a) (b)

Each has 72 steps, a consistency index of 0.49, and a retention index of 0.66. Differences between the two are restricted to the order of the Hardin and Hardin2 classes.

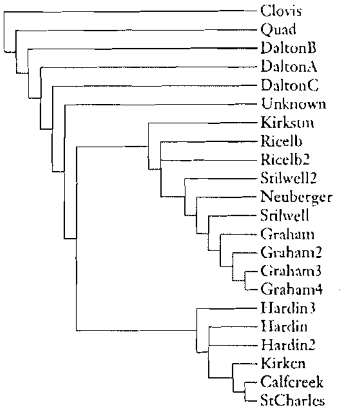
Figure 12.7
The Remaining Two of Four Equally Parsimonious Rooted Cladograms for the 22 Taxa Included in the Analysis



(a) (b)

Again, differences between the two are restricted to the order of the Hardin and Hardin2 classes.

Figure 12.8
Strict Consensus Tree for the Four Most-Parsimonious Cladograms



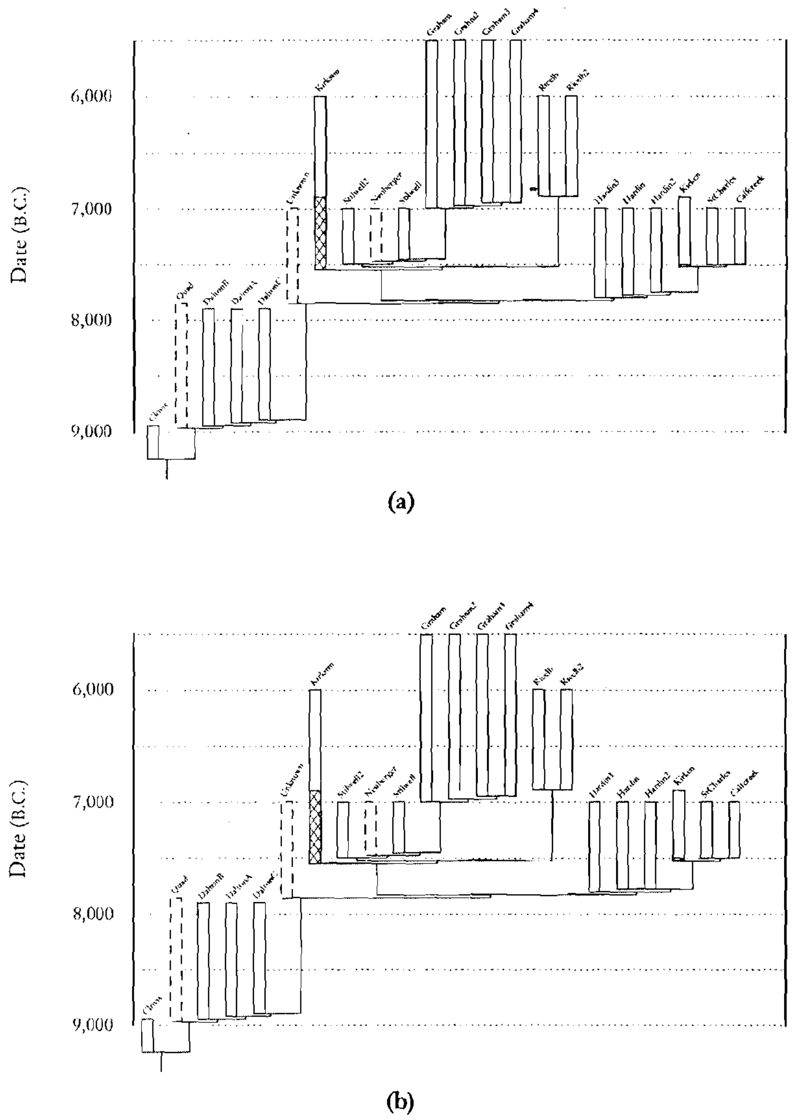
Because of the similarities among the four most-parsimonious cladograms, the majority-rules consensus tree is identical to the strict consensus tree.

Hardin and Hardin2. Through a rare set of circumstances, related to the position of Ricelb and Ricelb2, the majority-rules consensus tree and the strict consensus tree are identical. The tree is shown in figure 12.8.

In order to choose the best representation of the phylogeny, we compared the trees to the archaeological record by evaluating the congruence between the order of the classes in the trees and their known temporal ranges. Pictured in figures 12.9 and 12.10 are the four trees calibrated to the archaeological record, with the open bars representing the known temporal ranges of the points (see table 12.2 for assigned ranges) and the cross-hatched bars representing instances where we had to extend the taxa ranges in order to keep the logical consistency of the tree. Notice again that the only difference between the two trees shown in each figure is the placement of the Hardin and Hardin2 classes.

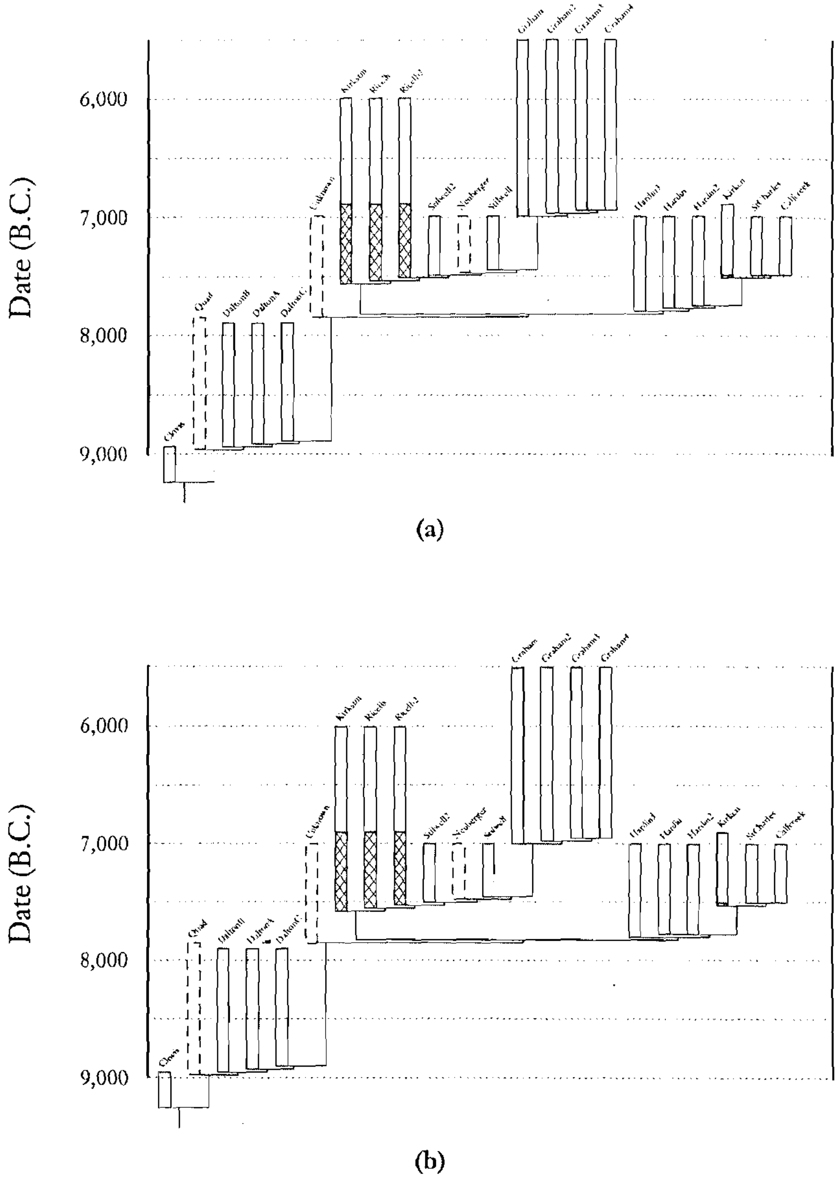
In instances where several classes have specimens from one established point type (e.g., Stilwell and Stilwell2), the first class with the type in the temporal ordering of taxa is given the full range of the point type, and subsequent classes with the type are given a more restricted range (e.g., the Stilwell2 class is given a range of 7500–7000 B.C., whereas the more derived Stilwell class is given a range of 7450–7000 B.C.). There are no "penalties" assigned to the trees in terms of correspondence to the archaeological record because classes with reduced ranges have specimens that are more derived and therefore would naturally come later in time.

Figure 12.9
Two of Four Phylogenetic Trees Calibrated with the Archaeological Record Created for the Four Most-Parsimonious Cladograms



The trees differ in terms of the splitting events connected with the Hardin taxa. Open bars represent known class ranges, cross-hatched bars depict temporal range extensions, and dashed-lined bars indicate estimated ranges for classes without clear temporal information. The minimal time interval between speciation events is 25 years.

Figure 12.10
The Remaining Two of Four Phylogenetic Trees Calibrated with the Archaeological Record Created for the Four Most-Parsimonious Cladograms

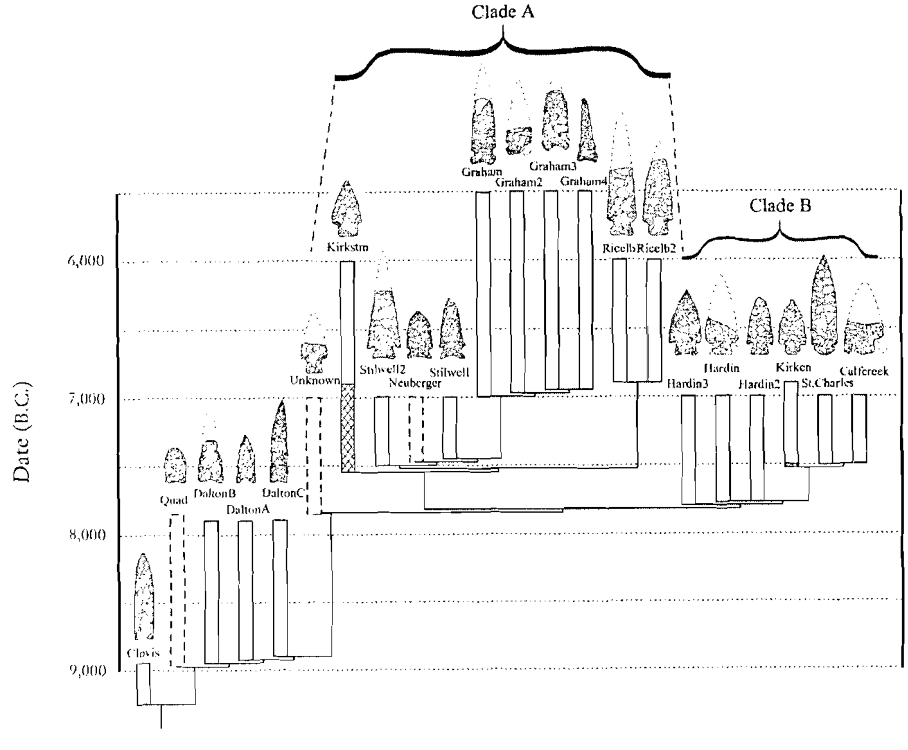


See the figure 12.9 caption for symbols.

We use bars with dashed lines to indicate classes that had specimens from unknown point types or from types with poorly defined temporal ranges, and we set their ranges based on what is known about the type and the position of the class on the tree. Although each taxon-origination event is depicted as being minimally twenty-five years apart, the gap could be considerably smaller. In theory there could be a speciation event over the course of one knapping session, which is virtually instantaneous in terms of archaeological time. However, if one or several speciation events occur in such a limited period of time, then other speciation events will have be proportionately longer. Therefore, we use twenty-five years only for the sake of convention.

Evaluating the trees in terms of congruence with the archaeological record, the trees in figure 12.10 are less acceptable because they require range extensions for three of the classes as opposed to one for the trees in figure 12.9. In

Figure 12.11
Phylogenetic Tree of the Most-Preferred Tree with Class Illustrations



Clade A comprises Kirkstm + Ricelb + Ricelb2 + Stilwell2 + Neuberger + Stilwell + Graham + Graham2 + Graham3 + Graham4, and Clade B comprises Hardin3 + Hardin + Hardin2 + Kirken + StCharles + Calfcreek. Open bars represent known class ranges, cross-hatched bars depict temporal range extensions, and dashed-lined bars indicate estimated ranges for classes without clear temporal information.

figure 12.10 Ricelb and Ricelb2 must be extended below 7500 B.C. in order logically to appear before the Stilwell2 class. If we add the number of years of extensions needed for each tree, those in figure 12.10 require 1975 years of additional range, whereas those in figure 12.9 require only 675 years.

The two trees in figure 12.9 are equivalent in terms of the archaeological record because they require the same number of extensions and have the same number of range extensions and ghost taxa. Thus, to decide between these two, we compared the arrangement of taxa to the consensus tree, under the premise that if a particular tree matches the consensus tree, then it has the most support in terms of character-state distribution. The tree shown in figure 12.9b, reproduced in more detail in figure 12.11, has more support in terms of characters and thus is the best hypothesis of projectile-point development.

Implications in Terms of Character Evolution

Viewing the tree in terms of hafting allows us to generate an overall picture of point evolution, but it does not allow us to formulate explanations as to why certain clades developed in the manner they did. However, one of the powerful aspects of using cladistics for examining technological change is that we can move down from the taxic level to examine historical change in individual characters. In theory almost every character change could represent a functional change in the performance of a projectile point, any of which could benefit or hinder its success as a weapon (Beck 1998). Characters such as weight, blade shape, width, and haft all affect how deeply a projectile penetrates its target, how much bleeding it causes, how accurately it can be propelled to the target, how far it can be effectively shot, how well the projectile will withstand impact, and even ease of manufacture (Christenson 1986; Hughes 1998; Musil 1988). The design of every projectile point represents a series of compromises among these factors and reflects the needs its manufacturer perceives as necessary for successful use.

Unfortunately, the results of cladistics cannot determine whether a character change represents a functional change in projectile-point design, nor do we have informants who can tell us why they changed a particular feature. However, the engineering properties of different characters can give us some insight (O'Brien and Holland 1990; O'Brien et al. 1994).

We selected six characters to monitor—IV (inner shoulder angle), V (lower notch angle), VI (tang-tip shape), IX (blade-to-base ratio), XII (notch shape), and XIII (neck-width/blade-width ratio (table 12.1). Characters VI, IX, and XIII were chosen because they are connected with the ability of a projectile point to withstand damage during use. Characters IV, V, and XII were selected because they are tied to certain aspects of the performance of a projectile point.

For character XIII, the strength of a point should increase with a lower neck-width/blade-width ratio because the neck is larger in proportion to the blade. This should reduce the effects of side slap or bending force during impact with either the target or the ground (Van Buren 1974). Although two dimensions that were not included in the analysis—thickness and cross section—also play a role (Cotterell and Kamminga 1992; Hughes 1998), a smaller blade will have less area to exert pressure on the neck than will a larger blade. However, the tradeoff for a smaller blade in proportion to the neck is that the penetration of the point could be affected because the blade will have less ability to create an opening through which the bindings can pass (Musil 1988).

The size of the base in proportion to the blade (character IX) should also be a measure of the durability of a projectile point. On the one hand, a proportionally larger base should be able to withstand more shock than a smaller base and be able to better distribute force across the shaft or foreshaft of the projectile, thereby lessening the likelihood of damage. In addition, bindings can be wrapped more effectively around the bottom of a larger base, which helps lessen the force of impact on a shaft. On the other hand, with an enlarged base there is a reduction in size or effect of shoulder barbs. This could reduce the ability of a point to cause bleeding (Christenson 1986).

Another component that possibly influences the strength of the base of a point is tang-tip shape (character VI). Although we have three states for this character—pointed, blunted, and squared—the main division in terms of strength is between pointed versus blunted and squared shapes. Blunted and squared tangs tend to create more robust bases than do pointed tangs. They might also allow for more secure hafting.

The lower notch angle (character V) also plays a role in how securely a projectile point can be fastened to a shaft or foreshaft. The closer the lower notch angle comes to 90 degrees, the more perpendicular it becomes in relation to the shaft, which should increase the ability of the bindings to keep the point attached to the shaft when it is withdrawn from an animal. Although this might be an advantageous characteristic in terms of reuse of projectiles, in some instances the desired effect might be to have the point remain behind in the target to cause additional tissue damage and bleeding.

The presence or absence of shoulder barbs on a projectile point is a factor of the inner shoulder angle (character IV) because any projectile point that has an inner shoulder angle greater than 90 degrees effectively has barbs. Functionally, barbs increase the ability of a projectile point to cause bleeding by holding the point in the target, which could cause more damage by further cutting brought about by backward pressure produced by the shaft. As Christenson (1986: 117) put it, "a wide, barbed point will rankle and cause more bleeding than a narrow, unbarbed one."

Despite the effectiveness of barbs in causing bleeding, there are tradeoffs that come with them in terms of durability and reuse because barbs themselves are relatively fragile (for examples, see Flenniken and Raymond 1986), and they are often associated with smaller bases and neck widths. The effectiveness of a barb is partially controlled by its angle, but the proportional size of the blade to the base also has an effect because the greater the width of the base in proportion to the blade, the less ability the barbs will have to hold.

Although there are six divisions for the shape of the notch (character XII), the importance of the character for this discussion relates the presence of a notch to the upper length of the notch margin versus the lower length of the notch margin. This character is obviously related to how a projectile point is hafted to a shaft or foreshaft but also to issues concerning reuse and material usage. According to Musil (1988: 376), lanceolate hafts are not very efficient because "a large amount of lithic material is discarded when [they are] broken, there is less opportunity for remanufacture, and [there is a greater possibility for] increased damage to the shaft upon impact." Similarly, Musil reasons that stemmed points are more efficient than lanceolate points because they allow for more rejuvenation of the blade before the point is exhausted or broken. Notched points are even more efficient because they can easily be renotched if the base is snapped off.

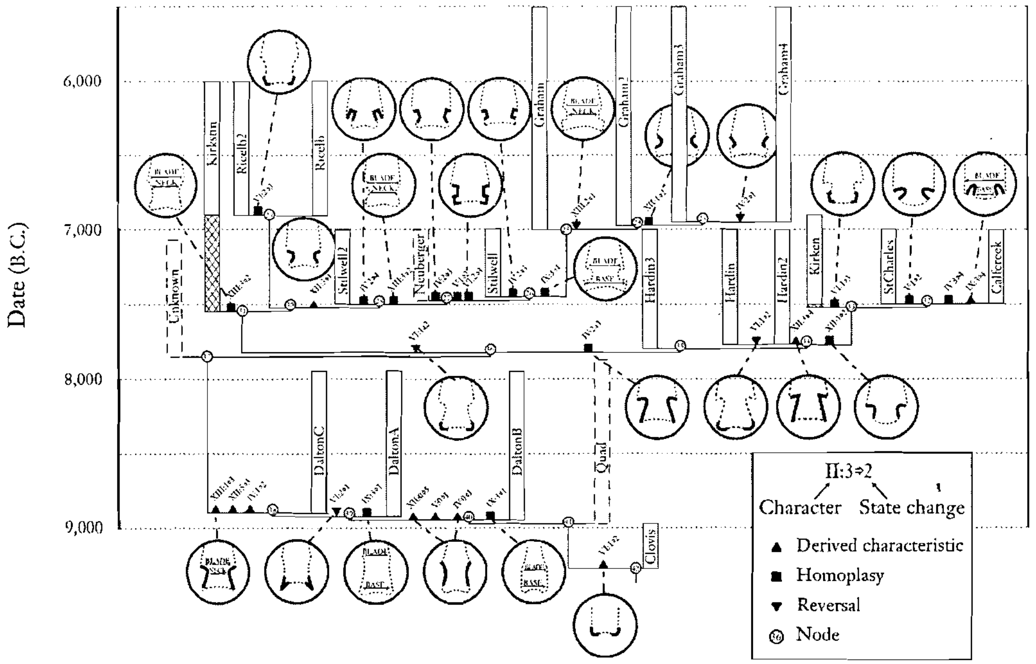
Figure 12.12 shows the preferred phylogenetic tree (from figure 12.11) with each of the changes for the six characters illustrated. Although the first change for the six characters occurs at node 42, where character VI changes from state 1 (pointed or rounded basal tangs) to state 2 (blunted basal tangs), the first important set of changes in the characters occurs at node 40. Here Dalton points presumably were initially ground on the lateral margins to the degree that lower section of the point came to resemble a broad crescent-shaped notch, and a slight shoulder was formed (denoted by character XII changing from 0 to 5). With this change the inner shoulder angle and lower notch angle originated, as character IV moved from 0 (no notch present) to 1 (1–45 degrees) and character V moved from 0 (no notch present) to 1 (136–180 degrees). Although these changes are depicted as occurring as early as 8850 B.C., it is impossible to determine from the current temporal data associated with the Dalton type whether this was the case. The creation of this new structure probably led to points becoming more securely hafted than straight-sided lanceolate points.

The next major change in the characters occurs after node 38. Character V remains the same, but character IV moves from 1–45 degrees (state 1) to 46–90 degrees (state 2), and character XII changes from a ground, crescent-shaped notch (state 5) to an asymmetrical notch, meaning the lower margin of the notch is twice as long as the upper margin, with a rounded interior (state 3). This new configuration created a stem in terms of large-scale hafting technology.

If we follow Musil's (1988) scenario, the change from lanceolate to stemmed hafts might have occurred because of the greater efficiency in terms of material use that stemmed points provided. In addition to this supposition, we propose that the decreased blade-width-to-neck-width ratio would have allowed the blade to create a larger opening in a target through which the bindings of the

Figure 12.12

Phylogenetic Tree of the Most-Preferred Tree with the Temporal Position of Characters IV, V, VI, IX, XII, and XIII Plotted along with Illustration of Each Character Change



The locations of character changes in the illustrations (circles) are designated by solid lines or text in combination with arrows specifying the direction of change. Dashed lines in the illustrations (circles) represent the nonchanging characters. All illustrations are proportional, with angles set to the midpoints of their ranges (e.g., a character with a range of 90–135 degrees would be drawn at 112 degrees) and blade, neck, and base widths drawn relative to one another. The type of character change is denoted by a symbol listed in the legend, and each node is labeled with a number for reference.

haft could pass. This change, in effect, could have increased the penetration of a projectile into an animal. However, the reduced neck-width-to-blade-width ratio might have also made the new stemmed points fundamentally weaker than the previous lanceolate points. Therefore, it can be questioned whether the new haft was more efficient in terms of reuse unless it provided increased protection for the shaft. Unfortunately, there is little in the way of experimental data that could determine this, one way or the other.

A division creating two major clades of Early Archaic–period projectile points (noted in figure 12.11) occurs after node 36, with one of the changes being character IV moving from state 2 (46–90 degrees) to state 3 (91–135 degrees). This new state is one of the defining derived characteristics for Clade B, despite its occurrence in classes in Clade A, and it does not change again on the clade with the exception of the Calfcreek class, where the angle becomes even more pronounced. In terms of morphology, this character change effectively makes the taxa in Clade B barbed. Based on the temporal range of the Hardin3 class on the following node, the change in character IV happened prior to 7800 B.C., but how much earlier is not resolvable.

The rest of the changes in characters IV, V, and XII for Clade B occur after nodes 34 and 32. One change of note in character XII occurs after node 34, where there is a reduction in the size of lower margin of the notch (state 3 to state 2). This modification created some points that traditionally would be considered corner notched depending on the width of the notch. Based on the position of the node, this change occurred approximately between 7750 and 7525 B.C.

After node 32, characters IV and V move in opposite directions. On the one hand, character IV moves from state 3 (91–135 degrees) to 4 (136–180 degrees) to roughly parallel the angle of character V, which creates a basal-notched configuration found in the Calfcreek class. On the other hand, character V moves from state 1 (136–180 degrees) to state 2 (90–135 degrees) to form the distinct corner notches present on the specimen of the StCharles class. Both of these character changes became fixed around 7500 B.C. and represent some of the last innovations in this clade along with one last change of note. Character IX changes on the Calfcreek class after node 32, when the blade becomes larger in proportion to the base, moving from state 3 (1.1–1.9) to state 4 (2.0–4.0).

The development of blunted basal tangs after node 36 is one of the defining features of Clade A, despite similar changes in the taxa of Clade B and its status as a reversal. After node 36, character IV changes from state 1 (pointed or rounded basal tangs) to state 2, which begins the development of more robust bases in Clade A. Subsequently, character IV changes from blunted (state 2) to squared (state 3) basal tangs on the main lineage after node 27 and independently after node 29 for the Ricelb2 class. Never does the character revert to pointed or rounded tangs. Because of the position of node 29 in relation to the Hardin3 class, this change had to have occurred before 7800 B.C.

The sequence of change in characters IV, V, and XII for Clade A represents an interesting case where the hypothetical ancestor has a different configuration than the taxa branching off the nodes. Following the departure of the Ricelb and Ricelb2 classes from node 30, the next three classes to arise all have hafts that would be considered as corner notched based on the angles of their notches. However, the ghost taxa from which these points branched appear to have been side notched. The incongruity begins after node 30, where character XII changed from 3 to 1 prior to 7500 B.C. This transformation involved a shortening of the lower margin accompanied by a "squaring" of the interior of the notch instead of a rounded arch. Although some points with this new configuration might be considered corner notched, it is likely that many would be classified as side-notched points, depending on factors such as the width of the notch and the shape of the base. The subsequent shift of character V after node 27 from state 1 (136–180 degrees) to state 2 (90–135 degrees) would have created points that undoubtedly would be classified as side notched. Thus it is likely, based on the character changes on the hypothetical ancestor, that side-notched points were present in the region around 7500 B.C.

The three taxa that branched off from the hypothetical ancestor after node 30 all had variations in character IV. After node 28 the Stilwell2 class branched off with a change from state 2 (46–90 degrees) to state 4 (136–180 degrees), which in this case made the inner shoulder angle roughly parallel to the lower notch angle. After nodes 27 and 28, both the Neuberger and Stilwell classes independently changed from state 2 (46–90 degrees) to state 3 (91–135 degrees). Each of these three character changes is a homoplasy. The shift to state 4 in character IV also occurs in the Calfcreek class, and the shift from 2 to 3, while obviously shared between the Neuberger and Stilwell classes, also occurs after node 36. All of these changes arise relatively close to each other in time, around 7500 B.C. Because of this temporal proximity, we suspect that the similarities are the result of horizontal transmission, although additional spatial information is needed to enhance this argument. Regardless, if the changes in character IV in the three taxa were the result of independent invention, they represent experimental offshoots from a lineage that retains an ancestral characteristic.

The alterations in characters IV, V, and XII were accompanied by changes in characters IX and XIII. After node 28, the neck-width-to-blade-width constriction ratio (character XIII) changed from < 0.60 (state 4) to 0.79–0.60 (state 3). This change likely occurred around 7500 B.C. on the hypothetical ancestor but also occurred independently after node 31 for the Kirkstm class before 7500 B.C. Further expansion of the neck in relation to the blade continued, and after node 25 the ratio changes from 0.79–0.60 (state 2) to 0.80–0.99 (state 1). However, based on the position of this character state in relation to the Graham class, this change likely occurred around 7000 B.C. and thus was not a rapid one. One change occurred for character IX, where the base became wider than the blade as the blade-to-base ratio shifted from 1.1–1.9 (state 3) to < 0.9 (state 1). This change occurred between 7000–7500 B.C., but further resolution is impossible.

Stepping back to compare Clade A and Clade B, both are similar in that notching arose out of stemmed technology twice. The initial steps toward notching are relatively similar if we compare the hypothetical ancestors from node 30 on Clade A and node 34 on Clade B, as both have similar inner shoulder angles and lower margin angles. Although the changes after node 34 are depicted as being earlier than those after node 30, in actuality node 34 could be as late as 7525 B.C. and node 30 as early as 7800 B.C., and thus they could have been coeval. If we subscribe to Musil's (1988) hypothesis concerning the efficiency of notched points over stemmed points in terms of material use, the move to notching in both clades is not surprising and provides an explanation as to why these clades parallel each other in this regard. However, in addition appears that development of the clades represents two different approaches to maximizing projectile-point efficiency.

It appears that the innovations of Clade A were directed largely towards increasing the strength and, consequently, the reusability of projectile points. Although taxa in the clade obviously remained pointed, there is a lack of development of features that could have enhanced killing power. Conversely, many of the developments in Clade B reflect efforts to improve the killing power of projectile points, which likely came at the expense of projectile-point strength. Our reasoning for these conclusions is based on trends in the patterns of character development in each clade.

There are two lines of evidence for projectile-point durability increasing in Clade A. First, changes in characters VI and IX indicate that bases became more robust. This trend first started with the division between Clade A and Clade B, when basal tangs became blunted and eventually the base became wider than the blade. As discussed, larger bases likely made points more resistant to impact shocks as well as dampened the load on the shaft of the projectile. Second, the size of the neck in relation to the blade (character XIII) increased over time. This new adaptation also would have increased the strength of specimens, although probably at some expense to penetration power because bindings would have been closer to the margins of the blade.

In addition to the possible increases in durability, another series of changes that might have increased point reusability is the decrease in lower notch angle (character V). As it moved closer to 90 degrees, this shift increased the perpendicularity of notches in relation to the shaft of a projectile, which likely increased how securely the bindings could attach the point to a shaft or foreshaft. Consequently, these points would more likely stay with the shaft of the projectile when being withdrawn or knocked loose. This effect was likely enhanced by the retention of the ancestral inner shoulder state (character IV, state 2), which precluded the development of barbs that would have made extraction more difficult. Although there was experimentation with barbs on the branches of the Stilwell, Neuberger, and Stilwell2 classes, this character did not change on the hypothetical ancestor. The lack of barbs also eliminated the potential of breakage of these weaker structures.

In a different trajectory, the development of points in Clade B seems to have been more focused on increasing their killing power. This conclusion is based on the development of shoulder barbs and the overall lack of character changes that might impede their function. The appearance of barbs is one of the defining characters of Clade B after node 36, which reaches ultimate expression in the Calfcreek class at the crown of the clade. Barbs would have not only caused more bleeding but also created larger openings for haft bindings to slip through unimpeded. There are no changes in the blade-width-to-neck-width (character XIII) and blade-width-to-base-width ratios (character IX), nor changes in the lower notch angle (with the exception of the StCharles class) that would have hampered these functions. In the Calfcreek class the blade-width-to-base-width ratio actually became smaller, which would have increased the effectiveness of its barbs.

The downside of the development of barbs and the retention of the ancestral states of characters V, IX, and X (as well as the derived state of characters IX in the Calfcreek class) was that point durability was never enhanced and possibly was reduced. This might be best represented by specimens in the Calfcreek class. Although points in this class were highly efficient killing implements, they are usually found with broken ears (O'Brien and Wood 1998; Powell 1995). Therefore, the strategy in using these points, and other points of Clade B, was that the potential for causing more damage upon a successful hit outweighed the risk of point breakage and loss.

Conclusion

We have outlined how cladistics can be used to derive explanations for technological change in the archaeological record. In terms of interpreting the results, there is a need for better understanding of the performance standards (Schiffer and Skibo 1987) of different characters. This information can be obtained through experimenting with the properties of different characters and examining breakage patterns in archaeological specimens.

From our analysis it appears that the rise of side-notched points to dominance in northeastern Missouri in the Early Archaic period came through a series of character changes that enhanced projectile-point durability. Although another, competing tradition arose that appears to have emphasized increasing the killing power of projectile points, the benefits that this tradition conferred did not outweigh its costs to its manufacturers.

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