SEVEN

WHEN TO RETOUCH, HAFT, OR DISCARD? MODELING OPTIMAL USE/MAINTENANCE SCHEDULES IN LITHIC TOOL USE

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Utilized and retouched stone flakes are found in varying proportions in all lithic assemblages, with some artifacts exhibiting signs of hafting and extensive resharpening. Various theories offer explanations for patterns in lithic reduction, hafting, curation, and discard, including the abundance, proximity, and opportunities to acquire replacement raw material, and past attempts to increase functional efficiency. This chapter asks whether differences in tool efficiency occur for unretouched, retouched, and unretouched hafted artifacts for scraping wood after manufacture and maintenance costs are factored in. Because wood and plant working are common activities identified on stone tools, and especially scrapers and flakes, in studies of past stone tool use (Anderson-Gerfaud 1990; Beyries 1988; Dominguez-Rodrigo et al. 2001; Hardy 2004, 2009; Robertson et al. 2009), no doubt owing to the necessity of manufacturing wooden tools for subsistence activities and self-defense, this research is of importance in understanding the selective pressures operating on lithic technologies and the organization of technology throughout human evolution.

Retouched stone artifacts, especially those thought to have been hafted, typically take pride of place in archaeological analyses and illustrations of lithic assemblages. Their rise in frequency at certain times in the past often serves as a marker of industrial change and is usually interpreted as improved technological efficiency, more specialized activities, or increased cultural complexity. The significance attributed to retouched artifacts often rests in the belief that they were shaped to a specific design, were targeted toward and modified by specific functions, and also formed important markers of ethnic identity and cultural sophistication (Hiscock 1988). Retouched artifacts also certainly required greater investment in time and labor to produce than unretouched flakes, and hence improved efficiency might be predicted from recent evolutionary models that suggest that greater investment in extractive technology – or *tech time* – should result in higher payoffs in subsistence returns (Bright et al. 2002; Ugan et al. 2002).

The significant role of retouched and standardized lithic tools has also featured heavily in theorizing about appropriate technological responses to risk and mobility, as seen particularly in discussions of reliable versus maintainable toolkits (Bleed 1986; Clarkson 2007; Hiscock 2005; Kuhn 1995; Myers 1989; Nelson 1991). Likewise, hafting a stone tool is commonly argued to increase the efficiency and precision of the work while also allowing smaller artifacts to be used (Keeley 1982). The likely greater reliance on hafting in the later Paleolithic is one of the major observations to be made about changes in lithic technology in human evolution (Clark 1968).

Some or all of these propositions concerning the important role of retouched and hafted stone artifacts are likely to be true in certain cases. However, technological analyses of the last few decades have also shown that retouched forms can be highly mutable and multifunctional, and retouch intensity appears to be as responsive to raw material availability, mobility, and economic risk, as it is to functional and ethnic concerns or greater investments in tech time to secure higher subsistence returns (Brantingham 2003; Clarkson 2005, 2007; Dibble 1995; Gordon 1993; Hiscock and Attenbrow 2003; Morrow 1997; Neeley and Barton 1994; Nejman and Clarkson 2008; Shott 1989).

Ethnoarchaeology has also eroded the sense that retouched artifacts are necessarily the most desirable or significant objects in an assemblage, providing many cases (particularly in Australia and New Guinea) where unretouched flakes were preferentially selected and rapidly discarded with little concern for retouching or imposing specific shapes on artifacts (Cane 1988; Hayden 1979; Shott and Sillitoe 2005; White 1969; Wright 1977). These observations of expedient use puzzled early typologists (Hayden 1977; Hiscock 1998; Holdaway 1995; Wright 1977), and led to a view that perhaps stone tool use in post-contact times reflected a loss of skill or knowledge about lithic technology, or that the conditions of use were unlike those of pre-contact times.

A number of significant usewear and residue studies have also shown that although certain retouched tool types are traditionally seen as designed for specific tasks, tight form–function relationships are typically illusory or non-existent and that past tool-users, as well as those documented in ethnographic times, were often agnostic about the choice of artifact type for a given task

(Anderson-Gerfaud 1990; Beyries 1998; Clarkson and Connell 2011; Hardy 2004; Hayden 1979, 1985; Robertson et al. 2009; White 1969; Wright 1977).

Again, although some of these statements about a close fit between tool efficiency and form could be true in certain cases, we set out here to show that some of our ideas about the relative significance and functional efficiency of stone tools, particularly retouched and hafted tools, may be unfounded.

Experiments conducted with student volunteers reveal some surprising results in terms of the differential efficiency of flakes modified and held in different ways. The results of these experiments inform the way we conceive of the principles governing the organization of lithic technology in past societies, and make sense of stone tool use among those traditional societies observed in recent times. In particular, the results of this study reveal that retouching and hafting are likely to be efficient strategies only in particular contexts, and that heavy reliance on unretouched toolkits will be the most efficient solution in many (but not all) cases. This argument is not new, and has been a feature of theoretical statements about the organization of technology for some decades (Nelson 1991; Parry and Kelly 1987), but empirical demonstration of the mechanical principles that determine when to employ different strategies offers new insight into the choices people might make about when to employ certain strategies.

THE EXPERIMENTS

The experimental study models the declining rate of wood removed using a flake in a scraping motion. The experiments entailed extended use of 15 specimens: 5 unretouched, 5 retouched, and 5 hafted flakes (Table 7.1). The tools were all used to scrape medium hard wood staves for 10,000 strokes with a stroke length of 30 cm each. The wood used was spotted gum (*Eucalyptus maculate*) with an air-dry density of 970 kg/m^3. In each case, experimenters drew the tool toward the user while holding the edge at a steep angle to the staff. The wooden staff was weighed after every 50 strokes of roughly 30 cm length, and the time taken to perform each 50 strokes was recorded.

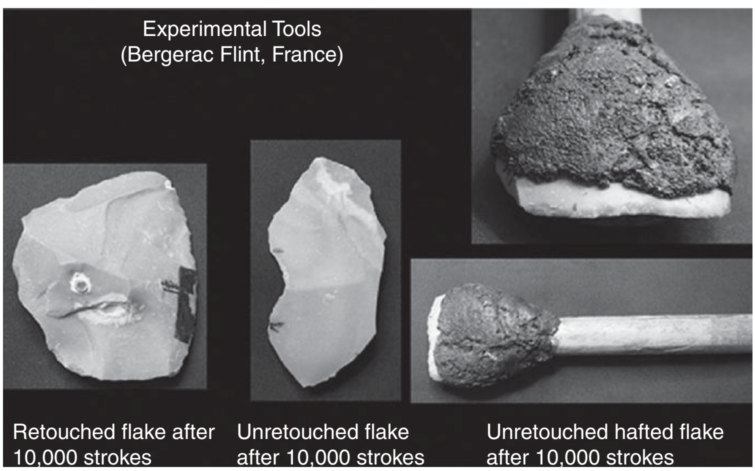
Grams lost from the staff after each 50 strokes is used as the measure of "gain" – that is, the amount of utility gained by the user for a particular task in a fixed period. From this we can also formulate a measure of "gain rate," being the rate of gain or loss in tool performance over a number of episodes of tool use. Gain rate can be used to determine whether a tool improves or declines in efficiency over time. The 10,000 stroke limit employed in this experiment equates to an average of about 2 hours of continuous use, or 3 km of continuous scraping.

All stone tools were made from high-quality Bergerac flint from France (Figure 7.1). Flint was chosen rather than an Australian stone material to

TABLE 7.1. *Details of individual specimens used in the experiment*

Specimen	Weight	Edge angle (degrees)	Final weight	Final edge angle	Total grams removed
Flake 1	78.0	48	77.76	64	562
Flake 2	84.3	50	83.78	75	910
Flake 3	84.8	42	84.68	58	1059
Flake 4	53.8	54	53.26	71	1337
Flake 5	49.8	36	49.52	75	540
Retouched 1	116.0	71.5	115.9	75	679
Retouched 2	162.2	75	161.7	83	574.6
Retouched 3	113.9	61	113.7	63	390
Retouched 4	120.4	63	119.9	64	601
Retouched 5	185.8	55	185.3	74	379
Hafted 1	186	NA	NA	NA	243.9
Hafted 2	280	NA	NA	NA	360.3
Hafted 3	267	NA	NA	NA	327.4
Hafted 4	190	NA	NA	NA	54.9
Hafted 5	210	NA	NA	NA	350

All specimens are made of flint. Edge angles could not be measured on hafted scrapers because of the resin mastic interfering with the measurement.



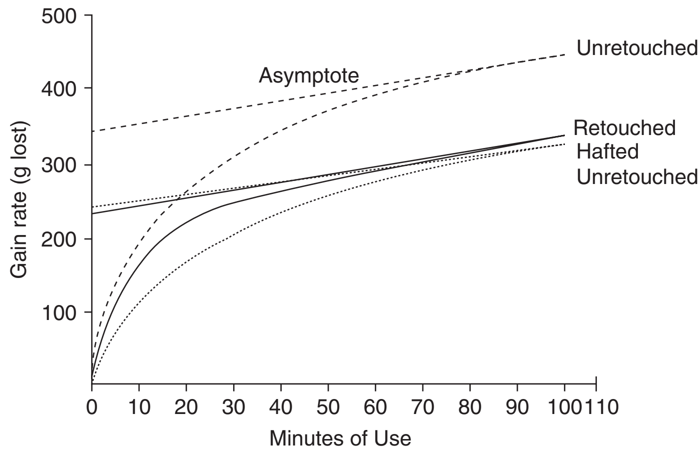
7.1. Examples of the experimental tools used in the experiments.

maximize global relevance, though in fact any high-quality cryptocrystalline silicate rock would likely perform in similar ways. The hafted specimens were set in a very tough spinifex resin (*Triodia* sp.) from north Queensland, Australia, and the hafts were made from pine or hardwood. All flakes were large enough to hold in the hand with ease, and had edge angles ranging from 45 to 65 degrees.

The experiments involved people using tools to scrape hard wood, aiming to do so in the most efficient way possible (i.e., adjusting angle of use and posture to achieve the best results possible). Collins (2008) recently performed similar wood working experiments measuring weight lost for a given number of strokes using a highly controlled and mechanized experimental design to test the differing efficiency of three different edge profiles. Although we did not mechanize our experiment, choosing to replicate real human motions instead, many variables were kept constant such as the species of wood and its provenience, stroke length, raw material type, and use action. The main disadvantage of this approach is that the specific interactions between variables cannot be isolated and only the overall patterns can be observed. The main advantage is that the actual motor habits of real people are replicated and individual variation can be examined. Our use of cylindrical staves meant that edge profiles tended to be less important in our experiment than would be the case in working flat planks of wood (cf. Collins 2008), and slightly concave, straight, and convex edges were all capable of making sufficient contact with the worked surface. In any case, concave edge profiles soon appeared on most tools (Figure 7.1). Edge angles for the retouched flakes were slightly higher on average (65 ± 7 degrees) than for unretouched flakes (46 ± 7 degrees), as often occurs when flakes are retouched (see Clarkson 2005; Hiscock and Attenbrow 2005). Because flakes with the same range of edge angles as those used in the unretouched experiments were chosen for retouching, our retouched population should accurately capture the results of retouching those flakes.

To ensure the same portion of the edge was used throughout the experiment, a 3 cm length of edge was marked, and in some cases colored black with ink to help locate the used portion of the edge and to monitor wear and flake scar accumulations. This 3 cm length of edge was used exclusively for the duration of the experiment. Edge angles and edge profiles were measured at the completion of every 1000 strokes, and the 50 stroke intervals were timed and recorded from time to time. To examine the changes to the morphology of the edge, and their relationship with efficiency, use wear was also recorded under low magnification (6.7×) by the authors (M. H. and C. H.), and tool edges were photographed under low magnification on both dorsal and ventral surfaces after each 1000 strokes. Usewear analysis consisted of counting the number of scars and the number of step and hinge scars, as well as employing a 4 rank system of edge rounding (0 – no rounding, 1 – light rounding, 2 – moderate rounding, 3 – heavy rounding). Edge angles could not be measured on hafted tools owing to the mastic interfering with the measurement; however, the range of initial edge angles was the same as that for unretouched flakes.

To ensure the drying of the wood or removal of soft bark were not major factors driving dropping efficiency in tool use, all staves were air dried for at least a week before use and the soft outer bark was removed before commencing the experiment.

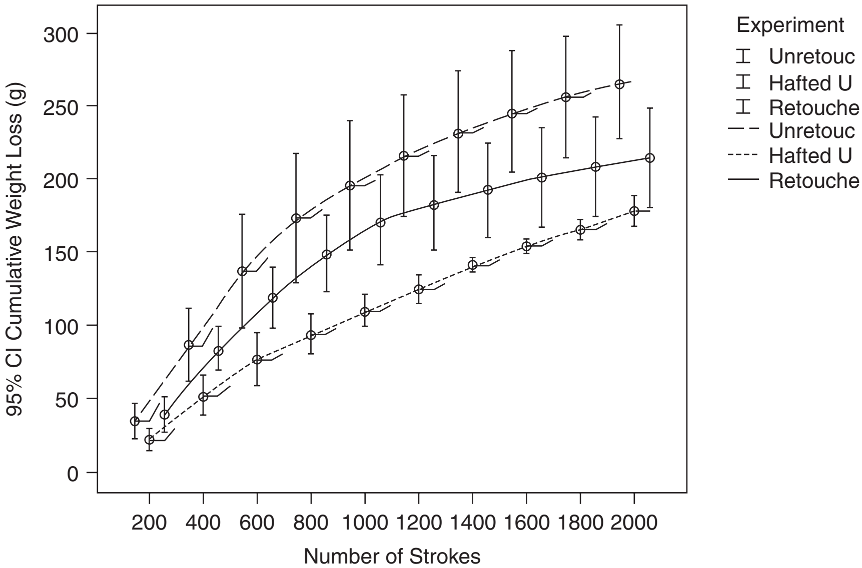


7.2. Experimental results showing the asymptotic nature of the declining gain curve over 10,000 strokes for all three experimental tool types. Times were calculated using an average of 1.3 strokes per second (45 strokes per minute). Asymptotes were not calculated.

RESULTS

The first experimental finding in this study is that declines in tool efficiency over the long term are asymptotic for all three kinds of tool use (Figure 7.2). This means that although all tools initially had a high rate of wood removal after each 50 strokes, the rate of removal declined through time, but at no time ceased to function entirely. The only exception was for hafted scrapers when the resin hafting broke and the tool critically failed. This rarely happened during scraping and the tools were rehafted and the experiment continued. The asymptote in Figure 7.2 is shown by the sloping line that comes close to intersecting the gain curve. Because the rate of gain continues to decline over the course of the experiment, and perhaps infinitely, the asymptote never actually intersects the curve, but gets closer with each observation.

An asymptote for wood working lithic tools means that scrapers could *in theory* continue to be used to the point were virtually no wood could be removed any longer, yet the tool could still be considered "functional" (albeit very inefficient), because some very small amount of wood could still be removed. This is important for modeling tool performance for scrapers because frequent critical failures (i.e., tool breakage) would drastically change the nature of tool use and replacement. For the purposes of this study, an asymptotic decline in tool efficiency means that decisions must be made by the user about when a tool is no longer functional and should be replaced, rather than the tool suddenly failing and necessitating replacement for the activity to continue. We are not suggesting that tools of this kind will never fail, only that this kind of activity is more likely to have to lead to decisions about retooling, and this makes modeling the tradeoffs between retooling and maintenance costs worthwhile.



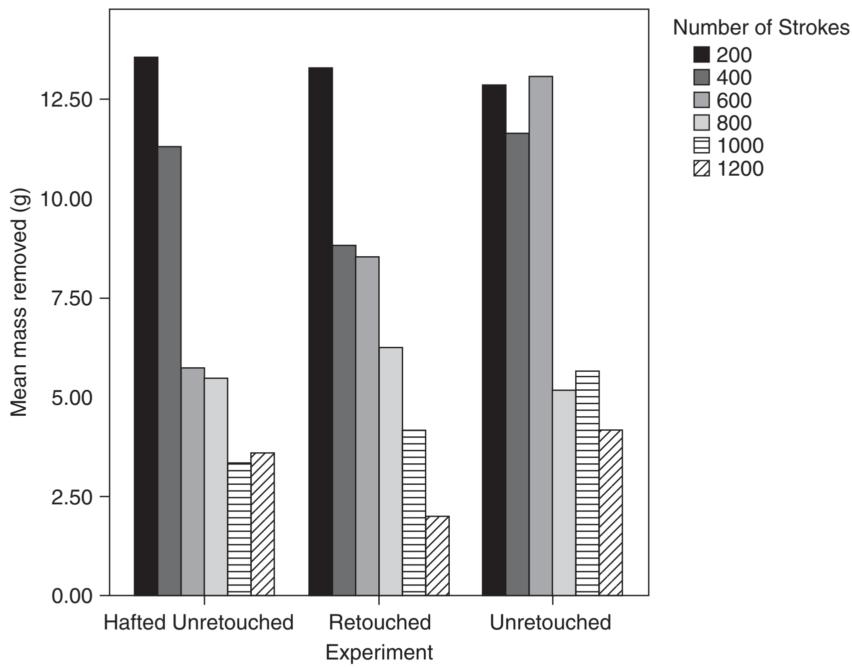
7.3. Confidence intervals for gain rate for each tool type over the first 2000 strokes.

Our results closely mirror those of Collins (2008); however, she used only unretouched flakes and continued her experiments only for 2400 strokes – too soon to establish the asymptotic relationship. Nevertheless, the similarity of our results gives us confidence in the merits of our approach given that Collins' experiments were mechanized and highly controlled.

The second and perhaps most significant finding is that retouched flakes are in fact far less efficient than unretouched flakes, both at the outset and over the longer use-life of the tool. This is still more surprising because the retouched artifacts had higher edge angles than unretouched flakes, a condition that is usually seen as increasing the efficiency of hard wood scraping (Wilmsen 1968:159). This is demonstrated by the initial steeper rate of gain for unretouched flakes and the steeper asymptote, meaning that even as gain approaches zero, it does so at a slower rate than for retouched or hafted scrapers. The differences in slope shown in Figure 7.2 are also supported by the average differences in total wood removed by each tool type after 10,000 strokes. Unretouched flakes removed an average of 881.6 g, retouched flakes an average of 524.7 g, and hafted scraper an average of 267.3 g.

Finally, hafted tools are found to be far less efficient than unhafted tools, and are much less efficient than unretouched flakes. This is a very surprising conclusion given that increased leverage and grip strength afforded by a solid handle should increase the force that can be exerted on the worked material and the precision with which it can be applied (Keeley 1982). Hafted tools have a much flatter rate of gain as well as a flatter asymptote, meaning that less material is removed at early and late stages of the work.

Figure 7.3 shows the confidence intervals for each tool type over the first 2000 strokes. The differences in efficiency are most pronounced in the first



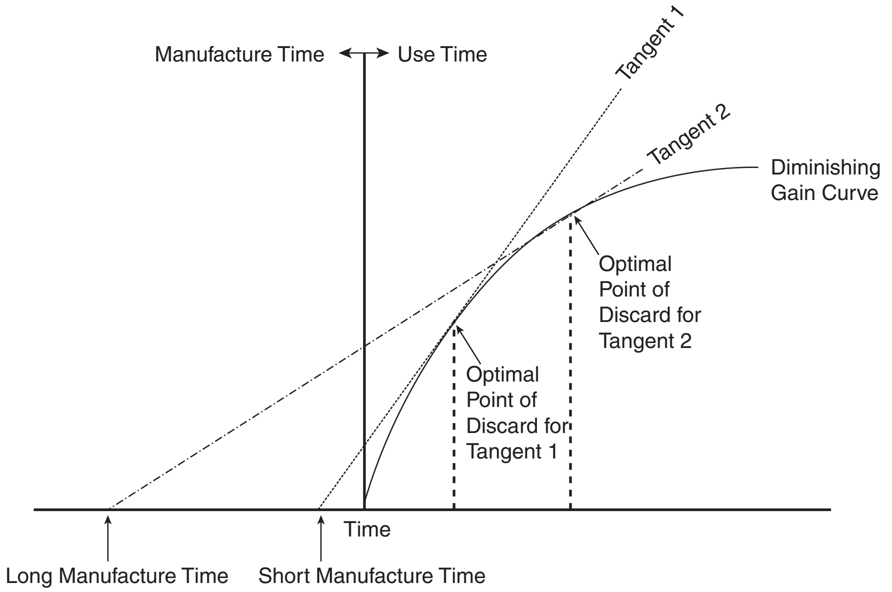
7.4. Relative performance declines for each tool type at 200-stroke intervals.

1000 strokes and then begin to flatten off. We can see from relative performance declines that retouched and hafted scrapers do slightly better at first (Figure 7.4) but that both kinds of tools dull more quickly than unretouched flakes. Unretouched flakes therefore maintain higher levels of performance over longer periods than either retouched or hafted tools.

MODELING OPTIMALITY IN SCRAPER USE AND DISCARD

It is possible predict the point at which maximum efficiency is reached for each type of tool, and hence the point at which it should either be replaced or rejuvenated by use of a model derived from the "marginal value theorem" and "central place foraging" models of Charnov (1976) and Orians and Pearson (1979) that are used extensively in evolutionary ecological studies. The same model has been used in archaeology to examine cases of field processing in which resources are located in a different place to where they were to be consumed (Beck et al. 2002; Bettinger et al. 1997; Jones and Madsen 1989; Metcalfe and Barlow 1992; Rhode 1990).

The model as presented here factors in manufacturing time for the artifact, such that any continued use of the tool would result in declining yields when compared to the cost of procuring a new tool. The point of optimal tool replacement/rejuvenation can be derived by fitting a tangent to the gain curve, in this case a diminishing gain curve over time (Figure 7.5). The model

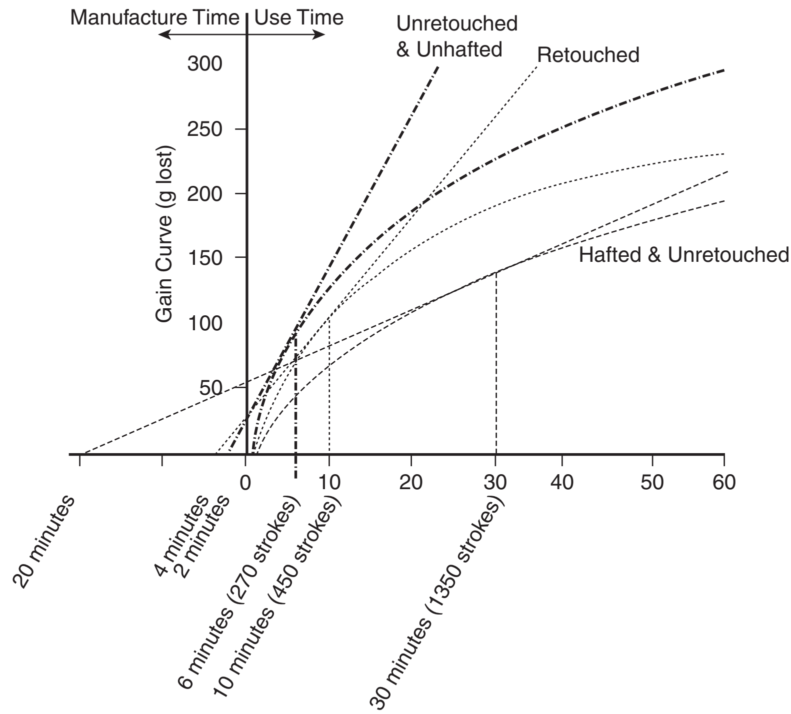


7.5. Model showing the effect of different manufacturing time (T) on overall gain rate. Factoring in manufacturing time (or tech time), enables the point at which maximum productivity has been reached (mo), such that continuing to use the tool would result in declining yields when compared to the cost of procuring a new tool.

takes into account both manufacturing time (to the left of the perpendicular line) and use time of the tool (to the right of the line). The longer the manufacturing time, the lower the angle of the tangent will be, as shown in Figure 7.5, and thus the longer the tool should be used to recoup the costs of initial manufacture. Hence, the tool with the short manufacture time intersects the gain curve much earlier in time, and while the tool is still operating at a higher rate of productivity (Tangent 1) than the tool with a much longer manufacture time.

In the case of scraper use, the model shown in Figure 7.5 indicates that a tool with a shorter manufacturing time and higher gain rate should be discarded more frequently, while at the same time, a shorter manufacture time and higher gain rate will mean the use of a more efficient technology overall. The bigger the fall off in gain rate (i.e., the more curvature in the gain curve), the more frequently tools should be replaced, because greater losses will be sustained by continuing to use the tool rather than procuring a new one.

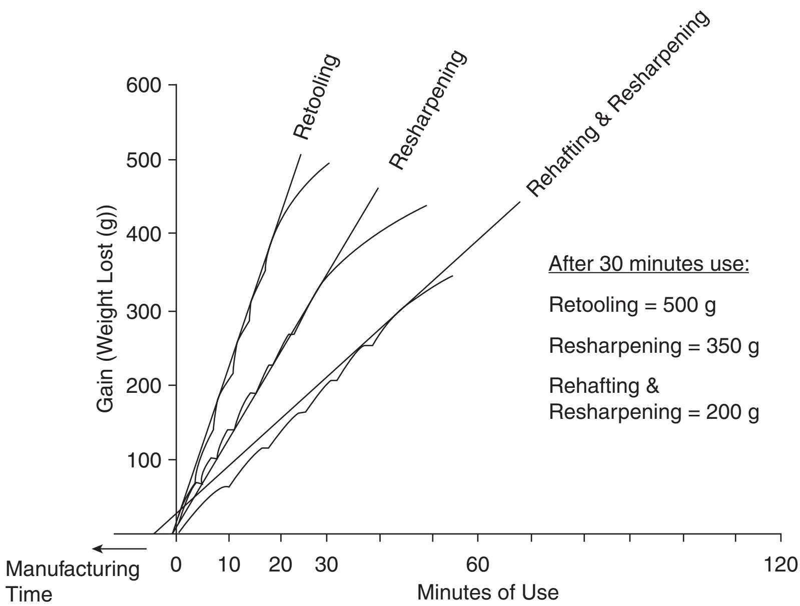
The model predicts that unretouched flakes, which in our study all had a very short manufacture time (average 2 minutes) and a rapid rate of increase as well as a rapid decline in gain rate, are most efficient for the first 270 strokes (compare also with Collins' (2008) 200 strokes for peak efficiency), or around 6 minutes of use (Figure 7.6). Using timed activity data, we know that retouched flakes take longer to make than unretouched flakes (an average of 4 minutes)



7.6. Model predictions for when to discard each tool type given different known manufacturing times.

and have a lower rate of gain, meaning optimal use is reached at around 10 minutes, or 450 strokes. At this point it is more efficient to procure another tool, or resharpen the tool than continue using it. Hafted tools obviously take the most time to make, as resin must be heated, shaped, and cooled before use, and the flake may also need shaping to fit the haft. This longer manufacture time (20 minutes), and lower gain rate, means that hafted tools are the least efficient and should be used for around 30 minutes. Tools should be used for this longer period to recoup the greater costs of manufacture, because discarding a tool soon after manufacture would mean spending significant time manufacturing another tool that could have been spent using the previous tool with no loss in overall efficiency. This situation invokes the concept of "sunk costs," whereby having invested significant time and energy in making a tool, it is worth accepting this as a start-up cost and continuing to use the tool for as long as possible rather than make a new one or attempt to procure a more efficient solution (such as obtaining fresh flakes).

The long manufacture time partly drives down efficiency in hafted scrapers, but the lower gain rate also requires explanation. We suggest that the extra force exerted on the edges of hafted flakes causes them to crumble more quickly, reducing efficiency. This proposition is examined further in this chapter.



7.7. The effects of maintenance time as well as manufacturing time on gain rate and overall efficiency as represented by the slope of the tangent.

We can take this modeling approach one step further by examining the effects of maintenance time on tool performance as well. Here the time taken to retool with a fresh flake, in the case of unretouched flakes, or resharpen in the case of retouched flakes, or to rehaft and resharpen in the case of hafted flakes, is factored into the model as flat spots representing the time taken to maintain the tool. A short initial manufacture time of only 10 minutes for the hafted tool was employed here (based on activity data from Australian Aboriginal examples of stone tool use recorded by Hayden in 1979), as in most cases people in Hayden's study tended to reuse a haft rather than make a new one each time. Maintenance episodes were repeated five times for each tool type. After each maintenance episode the tangent was refitted to the cumulative gain curve to determine the point at which the next retooling, resharpening, or rehafting episode should take place.

Figure 7.7 indicates that tool efficiency is heavily affected by retooling and resharpening, with the differences between overall gain (in terms of wood removed from a hardwood shaft) differing by up to 300 g after half an hour of work. Importantly, the overall slope of the line fitted to the gain curve for both unretouched and hafted unretouched flakes is to the right of the gain curve, meaning that continued use of this strategy actually results in increasing efficiency, because continued retooling or rehafting will continue to increase the rate of gain (i.e., push the line to the left) and hence overall efficiency of the tool. This makes sense particularly for the hafted scrapers given that continuing to use the tool will recoup the costs of making the haft and will improve the efficiency of the tool. The line fitted to the retouched gain curve, on the other hand, intersects to the right of the gain curve, meaning that this strategy will continue to become less efficient with time as continued use will continue to push the tangent to right, hence lowering overall gain rate.

Given that Australasian ethnographic accounts (one of the few such accounts we have, see also Gould 1980; Sillitoe 1988) indicate that wood working with stone tools to make spears, bowls, clubs, and hafts can take between 2 and 20 hours (Hayden 1979), such differences in efficiency would have huge effects on overall work time. According to the model shown in Figure 7.6, hafted scrapers should be replaced roughly every 30 minutes (determined from the intersection of the tangent with the gain curve in Figure 7.6), whereas unretouched flakes should be replaced every 6 minutes or so. An hour of work would therefore mean the most efficient strategy in terms of time (i.e., using fresh unretouched flakes) would also be the least efficient in terms of raw material use, consuming nearly 12 times the number of flakes as if the same flake were constantly resharpened!

ETHNOGRAPHIC COMPARISONS

If we compare the results of this experiment to ethnographic data, we find a close fit between model predictions and some real examples of stone tool use-life. Examining Hayden's (1980) data for tool use in the Australian Central Desert, for instance, we see that his informants chose to discard their unretouched flakes after an average of about 6 ± 5 minutes of use. This corresponds very well with the predictions made in this study for optimal retooling after about 6 minutes. Furthermore, Hayden found that people retouched their hardwood scrapers after 6.9 ± 11 minutes on average, again showing that tool efficiency dropped noticeably around this time. Most importantly, hafted retouched tools were used and resharpened for a mean overall use-life of 24.7 ± 22.9 minutes, suggesting that people greatly extended the use-life of these tools rather than incur the costs of rehafting.

Shott and Sillitoe's (2004, 2005) recent comparison of Wola unretouched flake use-life in the highlands of PNG and hafted end scraper (flake shaver) use-life in an Upper Palaeolithic site using survivorship profiles also sits well with this model. The unretouched flakes were all discarded early in the overall potential use-life of the artifact (around 6–11 minutes), while the hafted end scrapers were more likely to be completely used up (i.e., retouched to the point of exhaustion). That pattern can be explained as more frequent retooling to maintain high efficiency for low manufacture and maintenance costs, in contrast with prolonged use and curation of expensive hafted technologies to recoup large manufacture and maintenance costs.

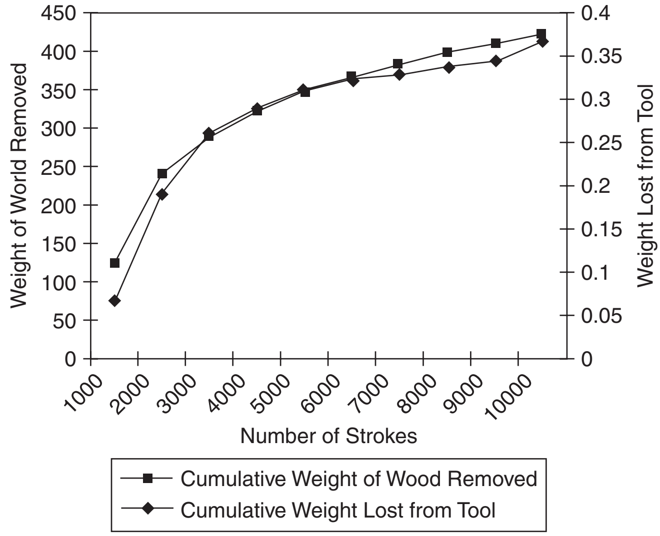
Data of a similar kind also exist for Ethiopian hide scrapers. These data show that resharpening was very frequent for hide scrapers (between 100 and 300 strokes) (Gallagher, 1977; Weedman 2000). However, because skin scraping is a very different activity with likely different rates of attrition of tool edges and a different use action, these data are unlikely to be directly comparable to our own experiments. Future experiments using a range of flake types to work hides will explore whether similar relationships hold for different activities.

USEWEAR PATTERNS

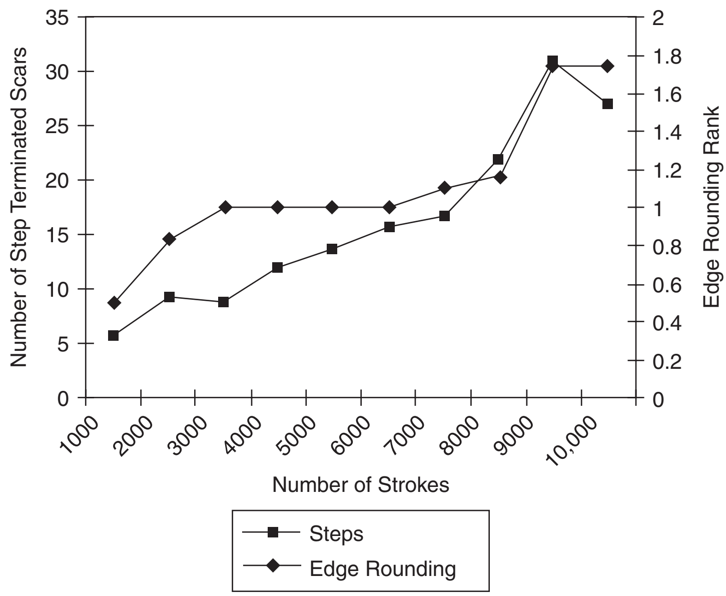
The use wear data obtained during this study offer substantiation of and explanation for dropping rates of efficiency in stone tool use. Figure 7.8 shows both the gradual mean cumulative weight of wood removed from the staves (square symbols) as well as the mean cumulative weight of stone lost from the edge of the unretouched flakes (diamond symbols). These two curves closely mirror one another and show that increasing wear on the tool's edge directly affects the rate of gain for scraping wood.

The type of damage to the edge is also important in determining the loss in efficiency to the tool edge. Figure 7.9 plots the mean cumulative accumulation of step terminated scars (square symbols) and edge rounding (diamond symbols) on the edges of the unretouched flakes. The two are also closely correlated, showing that step terminated scars increase first, stabilizing edge loss, followed by an increase in edge rounding. Both stepped scars and edge rounding increase together dramatically in the final few thousand strokes. In other words, as edges crush and become stabilized rather than continue to chip away, the stabilized edges begin to round, further reducing the efficiency of the tool. The same patterns are seen for retouched and hafted tools, but are not presented here. Retouched and unretouched tools also show substantial increases in edge angle as a result of edge attrition (Figure 7.10). Edge angles could not be measured on hafted scrapers owing to the resin mastic interfering with the measurement.

Finally, our usewear data may shed light on the reason for the poor performance of the hafted unretouched scrapers as against the unhafted ones, given hafting should increase leverage and force. Figure 7.11 shows the rates of increase in edge rounding and step terminated scars on hafted and unhafted unretouched flakes. The graph on the left shows that edge rounding is slower to form on hafted scrapers, whereas the graph on the right shows that step scarring accumulates more quickly on hafted scrapers, as the edge crumbles more quickly, perhaps due to the increased force that can be brought to bear on the hafted tool. As the edge is crumbling quickly over the 4000 strokes, edge rounding is unable to form, whereas it is able to form on unhafted

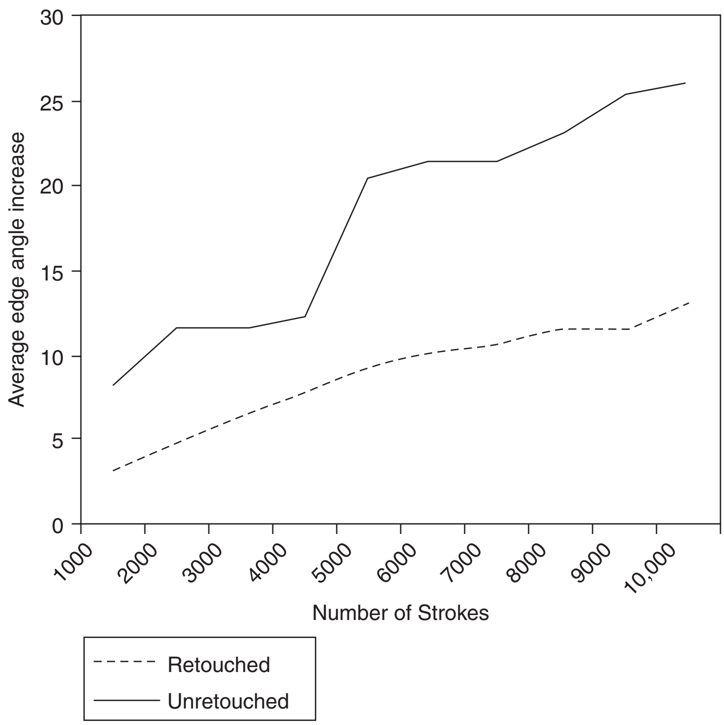


7.8. Mean cumulative weight of wood removed per 1000 strokes (left *y*-axis), and mean cumulative weight lost from unretouched flakes per 1000 strokes (right *y*-axis).



7.9. Mean cumulative rate of increase in step terminated scars for the 3 cm used edge (left *y*-axis) and mean edge rounding rank for the utilized edge (right *y*-axis).

scrapers. Stepped scarring drops off on hafted scrapers after 4000 strokes and edge rounding beings to climb steeply. These data suggest that the greater force exerted on hafted tools causes them to fail more quickly and hence to have a lower rate of gain when compared to unretouched flakes.

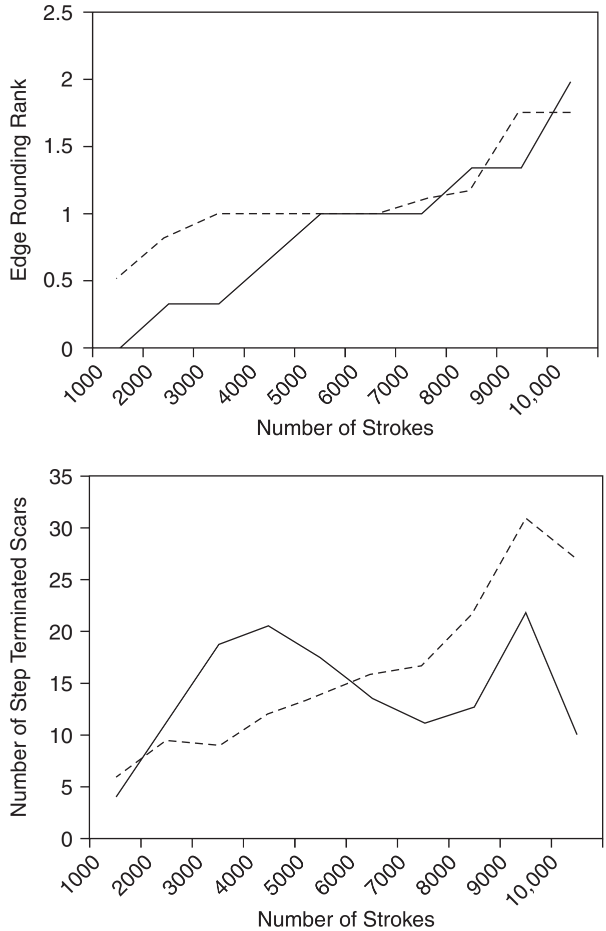


7.10. Average increases in edge angle (in degrees) over the course of the experiment for retouched and unretouched edges.

DISCUSSION

The question arises that if retouch and hafting are so inefficient, and technical systems concerned with subsistence returns such as making weapons and domestic tools of wood are likely to be under heavy selection, why do it at all? The model here predicts that people should retouch only if they have insufficient raw material to resupply themselves constantly with fresh sharp flakes, remembering that maintaining the most efficient use of unretouched flakes means most likely consuming around 12 times the amount of raw material per hour. It probably also makes sense to haft if you cannot hold the flake effectively in your hand. All the flakes in our experiments were of large enough size to be easily held in the hand. It would be worthwhile testing whether using very small flakes results in big declines in efficiency that might be offset by hafting. It is expected that this would be the case.

There is no doubt that retouching an artifact once it becomes dulled increases its efficiency, at least temporarily. If new flakes are not available, then retouching an implement makes sense, even though a retouched flake always performs more poorly than a fresh flake. Retouched flakes also dull faster than unretouched flakes, and the option to retouch means one must continue to



7.11. Comparison of edge rounding (upper) and stepped scar formation (lower) on unhafted (broken line) and hafted (solid line) unretouched scrapers.

retouch frequently to maintain high efficiency levels. Our experiments also revealed that retouching an artifact attached to a handle with very strong spinifex resin almost always resulted in damage to the hafting. Hayden (1979) and others have made the same observation. Retouching a hafted scraper in the haft therefore may also entail undesirable rehafting costs, further increasing maintenance time and driving down tool efficiency and further increasing the value of prolonging the life of the tool.

There are of course many situations in which hafting is vital or dramatically changes what is possible with stone tools, but scraping wood when large unretouched flakes are available is probably not one of them. Drill technology, projectiles, and very fine engraving work involving lithic tool bits all likely require hafting to function well.

Our results therefore suggest that retouching is likely to be an important strategy when raw material is scarce or resupply is unpredictable, and that use of unretouched flakes will be the most efficient strategy when raw materials are locally abundant or at least consistently restocked. Uncertainty over raw material supply may pertain when raw material is simply rare in the landscape, or when people are highly mobile and cannot carry large quantities of raw material around with them. In other words, increasing mobility and uncertainty over opportunities to reprovision should mean that people must curate the toolkits they carry with them, and as flake tools dull quickly, resharpening is the best option for maintaining efficiency. Because toolkits often need to be small and portable during periods of high mobility, hafting would be an effective means of employing small tools, and of transporting them (Kuhn 1995). Conserving tools, however, means accepting drops in efficiency.

Alternatively, we might also predict that when raw material supply is limited or unpredictable, the continued manufacture of small-sized flakes from cores and larger flakes will also be an efficient strategy, rather than extensively retouching scrapers. Such small artifacts appear to predominate at certain times and places, such as in the Mousterian (Dibble and McPherron 2006), and in assemblages dominated by small bipolar artifacts (Hiscock 1996). We might also expect to find more signs of hafting given that the loss in efficiency that stems from greater difficulty in gripping the tool may be compensated for by investing greater time in manufacturing and maintaining a haft. The conclusions drawn from this study suggest that greater efficiency in wood working is obtained from frequent retooling with fresh sharp flakes. If these can be obtained only by removing usable flakes from small cores and flakes, then this may be the most efficient strategy for maintaining a supply of highly effective tools when raw material supply is limited. Such an approach might explain the preponderance of technologies such as truncated faceted and kombewa flake reduction in the Mousterian and Oldowan (Dibble and McPherron 2007), and may justify the sometimes extreme reduction of small freehand and bipolar cores.

This rapid depletion of tools and the rapid drops in efficiency that accrue from conserving them when equipped only with small hafted retouched tools also provide a good reason to schedule heavy woodworking tasks to periods of down-time in base camps that are stocked with raw materials (Binford 1980; Torrence 1983, 1989). This suggests that provisioning frequently and predictably used places with stockpiled raw materials would be an effective strategy for increasing the efficiency of wooden implement manufacture and maintenance within high-mobility land use systems. This is exactly what land use and provisioning models predict (Kuhn 1995; Nelson 1991; Parry and Kelly 1987), based on observations of hunter-gatherer behavior and archaeological assemblage variability.

Finally, shifts from so-called expedient flake assemblages to highly retouched and curated ones would be expected on the basis of results obtained in this study to correspond to increasing uncertainty about raw material supply (or changes in task that required specialized hafted tools), such that small tools had to be curated during more frequent periods of high mobility and uncertainty about opportunities to reprovision. In short, maximizing efficiency through the use of many unretouched flakes for short periods would be increasingly sacrificed for the security of a portable supply of small hafted, but less efficient, tools.

This work may also have implications for our understanding of scraper typology and assemblage formation. It would seem that initially retouching a flake for hard wood scraping is a bad idea, if the edge is already suited to the work. Although there may be cases in which retouching an edge to say, change the edge angle, may provide benefits above those obtained by using a fresh sharp edge, our experimental results would seem to suggest that in most cases scraping hard woods should begin with unretouched edges and proceed to retouching only when raw material must be conserved. The notion that people might retouch a flake to "turn it into a scraper" before use would therefore seem contrary to efficient tool use, and would also go against ethnographic observations of people starting out wood working with a fresh unretouched flake. This would suggest that reduction continuums in scrapers should begin with unretouched flakes, and that unused portions of the edge might be utilized before beginning retouching the edge. This is an easily tested argument and would bear consideration for future examination of the relationship between tool reduction and function (see Connell and Clarkson 2009). However, we also note that heavy use wear on our scrapers often resembled light retouch, and discriminating between retouch and use wear may not be easy, even microscopically.

CONCLUSION

Our experiments would suggest that correctly tailoring use-maintenance schedules was likely an important issue in prehistoric economies, and should be an important concern for a wide range of subsistence technologies. As Frison commented after performing experiments using composite spears armed with Clovis points to inflict lethal wounds on freshly culled African elephants:

> raw-material procurement, manufacture and maintenance of weaponry... are more time consuming than most investigators realize, but their importance cannot be minimized in hunting societies. Failure of Clovis hunters to maintain weaponry in top condition would have negatively affected not only the economic process but would have increased the probabilities of self injury and/or death. (Frison 1989:783)

This statement captures two important points made in this chapter: (1) that tech time can be considerable, and if not properly managed can adversely affect the efficiency of resource procurement, and (2) that failing to properly maintain tools can potentially have dire effects in risky situations and may lead to decisions to forgo a certain amount of efficiency for increased reliability (e.g., retouching, hafting, overdesigning, use of redundant parts, etc.) (Bleed 1986). Both statements should be true for subsistence technologies of all kinds, including processing technologies such as grinding stones; primary extraction tools such as digging sticks, spears, and traps; as well as those tools used to make extractive tools. Even manufacturing, hafting, and resharpening the simplest of tools – stone wood scrapers – can be considerable, as demonstrated by this study, and archaeologists should begin to factor such considerations into reconstructions and explanations of past decisions about whether to haft, retouch, or retool, as this may have major implications for the choice of strategies at different times in different places in the past.

The main conclusion this study has reached is that prehistoric tool users should in many cases have retouched their woodworking toolkits only when replacement material was scarce and/or unpredictable or when manufacturing costs were high (e.g., hafting). The exceptions would be in cases in which the task could not be carried out except by hafting (e.g., drills, projectiles, delicate engraving, adzing, etc.). Hafting probably offered a solution to transporting small tools and making them effective but offered few other advantages, at least for wood scrapers used in this study. This supports existing theoretical notions about the optimal organization of technology. Increasing mobility may therefore provide a better explanation for the transition to small, retouched, and hafted toolkits in many contexts than other explanations. We can predict, therefore, that when replacement raw material is available and need not be conserved, we should find many minimally used and discarded unretouched flakes and few retouched flakes. When raw material conservation is a priority, we should expect to see many retouched flakes, with the degree of use-life dependent on the severity of raw material restriction. We should rarely expect to see discarded hafted unretouched flakes in any context, unless they are for very specific functions or very small in size, as this would be the least efficient form of tool use of all. We should also expect to see signs that people have made use of most or all of the useable unretouched portions of a tool edge before proceeding to retouch the artifact. Because retouching will remove prior signs of use in many cases, specimens would have to be carefully chosen to test this hypothesis.

Although the power to generalize from limited wood working experiments of this kind has its limits, archaeological investigations of the relationship among manufacture, maintenance, and use have enormous potential to develop these hypotheses further and test them against real assemblages. Sadly, the unretouched component of most assemblages is rarely examined for signs of use, and it may be difficult at present to determine the extent to which past tool users made decisions about whether to replace or extend their supply of tools. Connell and Clarkson's (2011) recent analysis of scraper use in northern Australia demonstrates that past tool users were keenly aware of the functional proclivities of their tools, and often adjusted task associations to fit the changing nature of the tool edge as resharpening continued. If subtle differences in the efficiency of scraper edges of different kinds for different tasks could be detected by past tool users, then it is likely that past foragers also made calculated decisions about toolkit design and use-maintenance schedules. Examination of the relationship among raw material procurement, tool size, mobility, and reduction intensity should therefore continue to play a fundamental role in understanding the dynamics of past tool use and provisioning strategies.

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