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Experiments to Investigate the Effects of Heat Treatment on Use-wear on Flint Tools

By DEBORAH SEITZER OLAUSSON[1]

A series of twenty controlled experiments was undertaken to determine if heat treatment alters the speed, intensity, or appearance of wear on the edges of flint tools. Four hypotheses were tested with the following results: Heat-treated tools wore more quickly and with more severity than tools which had not been heated. When used in the same fashion and on the same materials, heat-treated flakes showed longer microflake removals from use than did non-heat-treated flakes. The use of these flint tools yielded more step and hinge flake terminations on the heat-treated tools than on the non-heat-treated tools. Flake scars from microflaking due to use had a shiny surface on flints which had been heat-treated, while such surfaces were matt on unheated materials. The results suggest that these effects should be taken into consideration when studies of use-wear are undertaken.

INTRODUCTION

It has been claimed that paleo-Indian man in America used thermal pretreatment as much as 10,000 years ago to improve the workability of his chertlike materials (Crabtree and Gould 1970, 196). Ethnographic accounts from the nineteenth century have hinted at the occurrence of this process among stone-using peoples in various cultures world-wide (e.g. Mandeville 1973; Hester 1972). More recent experiments by many modern workers, led by Don Crabtree, have established what changes occur in cryptocrystalline materials following heating. The benefits most often claimed as resulting from heat treating are: greater ease in workability of an otherwise 'tough' material; a decrease in the occurrence of step and hinge flakes; longer, larger, more well-controlled flakes; an increase in compressive strength; and the production of sharper edges (Crabtree and Gould 1970, 194; Weymouth and Mandeville 1975, 66; Flenniken and Garrison 1975, 129–31; Crabtree 1967, 14; Bleed and Meier 1980, 503; Collins and Fenwick 1974, 138; Purdy 1974, 48; Schindler *et al.* 1982).

Several researchers have suggested that the process at work here is a fusion of the material, resulting in a more vitreous quality during fracture. Impurities in the silica material serve as fluxes to fuse the microcrystals of the material more closely. This means that, in fracture, crystal boundaries are no longer interfering with the removal of flakes (Purdy 1974, 46–52) and the result is a more homogeneous material which fractures like glass (Mandeville 1973, 199; Bonnichsen 1977, 186–87; Flenniken and Garrison 1975, 128; Weymouth and Mandeville 1975, 66–67).

However, more recent work by Schindler *et al.* (1982) on jasper from Pennsylvania has indicated that the reduction in fracture toughness in Bald Eagle Jasper following heating has to do with the decomposition of goethite to hematite. Thermal alteration in the temperature range 100°C–300°C decomposes goethite to hematite, leaving a structure of hematite crystals between alpha-quartz regions. The goethite decomposition leaves about 25.7% void space, so that the hematite crystals are extensively microcracked away from the quartz and to some extent from each other. The authors claim that it is these microcracked hematite 'channels' that cause the decreased fracture toughness and increased workability of the jasper (Schindler *et al.* 1982, 532–35).

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Whatever the underlying cause, however, the result is that the very qualities which are sought after, in terms of greater ease in flakeability, can be undesirable in a tool designed to be used for certain tasks. For instance, heat treatment reduces the tensile strength of materials (Weymouth and Mandeville 1975, 66; Collins and Fenwick 1974, 137). Purdy found that heating silica material to 400° C for 24 hours and removing it immediately from the oven reduced its tensile strength by 45% (Purdy 1974, 48), while the study by Schindler *et al.* (1982, 532) showed that heat treatment decreases Bald Eagle Jasper's resistance to fracture to about one half its original value. The significance of this for those dependent on stone tools is that heat treatment alters the physical characteristics of materials, yielding a sharper cutting edge which is good for cutting soft substances but which can break when used on hard or tough ones (Sollberger and Hester 1972, 181). Thus it was probably not desirable to use thermal alteration in the manufacture of drills, scrapers, adzes, etc., when a tougher, stronger tool was needed and extreme sharpness of edge was less important (Crabtree and Gould 1970, 194).

Given the fact that termal pretreatment so alters the physical qualities of silica materials, it is not unreasonable to postulate that heat-treated materials will react differently from raw materials when subjected to the stresses of use. The purpose of the brief series of experiments related here is to determine if heat treatment alters the speed, intensity, or appearance of edge-wear occurring on flint during use. If it should prove to be the case that such alterations occur, then the edge-wear specialist who suspects that the tools in the collections he studies may have been heat-treated must be aware of differences in edge-wear which arise due to this physical change (Odell 1982, 24). It is also important to know how heat treatment affects an edge intended for use, since such knowledge was important for the aboriginal users in their decision of whether or not to heat-treat a given raw material.

Several hypotheses, based on what is known about the effects of heat treatment, could be set up to predict expected outcomes:

1. Because heat treatment reduces the hardness or toughness of a flake's edge (Crabtree and Gould 1970, 194; Sollberger and Hester 1972, 181; Schindler *et al.* 1982, 532), heat-treated flakes should wear more quickly and/or more intensely than non-heated flakes.

2. Because heat treatment allows the removal of longer flakes (Bleed and Meier 1980, 505; Flenniken and Garrison 1975, 129; Collins and Fenwick 1974, 138), heat-treated flakes should show longer microflake removals from use than unheated flakes.

3. Because heat treatment reduces step and hinge flaking (Weymouth and Mandeville 1975, 66; Flenniken and Garrison 1975, 129; Collins and Fenwick 1974, 138), heavy use will yield fewer such terminations on heat-treated than on non-heat-treated flakes.

4. Because heat treatment causes subsequent flake scar surfaces to be glossy (Mandeville 1973, 183; Crabtree and Butler 1964, 1; Collins and Fenwick 1974, 137; Schindler *et al.* 1982, 535), the scars from flakes removed from heat-treated tools during use should be glossy.

A short series of experiments was set up to try to test these predictions.

PROCEDURE

Since the aim of the study was to test for the effects of heat treatment, an attempt was made to control for all other variables which might affect edge-wear during use.

Three cores of flint of Senonian age from the chalk deposits at Kvarnby, Sweden, provided the raw material. This flint is of excellent quality: glossy black with a fine-grained homogeneous structure and a thin chalk cortex. Flakes were removed from two cores, termed A and C, using a hammerstone and an antler baton respectively. The flakes were allowed to fall to the floor. Small slabs of flint were sawed from a third core, core B, using a geological diamond saw. The original intention had been that all the flint samples should be produced this way, so that their morphological characteristics could be more rigidly controlled. However, it soon became apparent that sawing flint was a time-consuming process which rapidly wore down the geological saw. Further, the striations from the saw on the faces of the slices made it difficult to distinguish edge-wear (see pl. 6).

From the flakes thus produced, 32 were chosen from core A and four from core C, while four slabs from core B appeared to be suitable despite the above reservations. Some of the flakes were retouched to various angles with an antler baton or hammerstone, while others were left as they had come from the core. The 40 flakes and slabs were then examined under a binocular microscope at 16x and 40x magnifications, and the edge showing the least alteration due to manufacturing processes was located and marked. Any wear already present on this edge was recorded for each piece. Recording consisted of verbal descriptions of the nature and location of wear along the edge, and of photographs taken at 15x magnification. Because of the subjective nature of such description, much reliance was placed on comparing the appearance of tool edges during use with the photographs taken prior to any use. The following morphological characteristics were also recorded for each: flake weight, length (longest axis), width (perpendicular to the length), edge angle (Wilmsen 1968), edge thickness, edge morphology (e.g. 'convex', 'concave', 'irregular', 'straight') and, if retouched, by what means (fig. 1).

Primarily on the basis of edge angle and edge morphology, but taking into account edge thickness and general morphology, the flakes from each core were matched up into pairs, yielding sixteen pairs from core A and two each from cores B and C, for a total of twenty pairs of flakes.

Previous experiments with heat treating Kvarnby flint had indicated the times and temperatures needed to effect structural changes in the flint (Olausson and Larsson 1982, 22). One of the flakes from each pair was placed in a sand bath and heated in a laboratory oven according to the following schedule:

8:00	Flakes placed in oven and temperature raised to 100° C
9:00	Temperature raised to 200° C
10:00	Temperature raised to 250° C
11:00	Temperature raised to 300° C
12:00	Temperature raised to 350° C
15:00	Temperature raised to 400° C
17:00	Oven turned off

Thirty-six hours later the flakes had cooled to room temperature and could be removed.

Following this, both the dorsal and ventral surfaces of the chosen edge on each flake were photographed prior to use, in order to provide a basis for comparison after use.

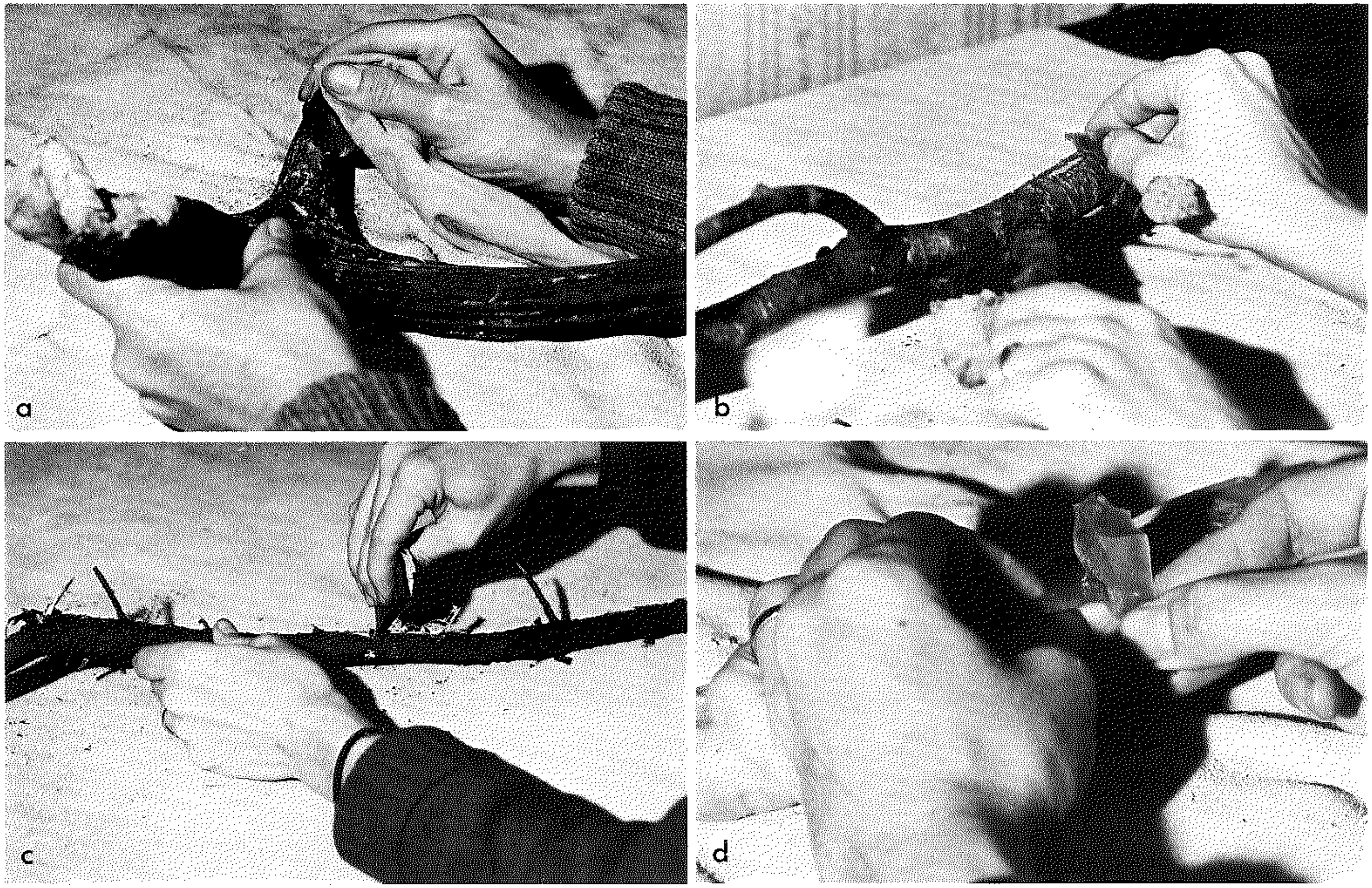
It was then necessary to determine what mechanical action and worked material the flake pairs could suitably be used on so that they would be effective but would not break from unnecessary stress. The aim of the experiments was not faithfully to reproduce conditions under which use-wear was produced on pre-historic tools, so that mechanical actions were kept as simple and controlled as possible (cf. Keeley 1980, 7–8), and no abrasive materials were introduced (Brink 1978). To avoid the necessity of experimenting to determine the most appropriate actions and worked materials for the flakes, it was decided to adapt Keeley's (1980) experimental results to fit the present series. On the basis of the best fit with edge angle, edge morphology and the general appearance of the flakes with these characteristics on Keeley's experimental tools, appropriate experimental actions and

MORPHOLOGICAL DATA										EXPERIMENTAL DATA			
EXPERIMENT NO	FLAKE NO	HT ?	WEIGHT (g)	FLAKE LENGTH (cm)	FLAKE WIDTH (cm)	EDGE ANGLE	EDGE THICKNESS (cm)	EDGE MORPHOLOGY	RETOUCH	MECHANICAL ACTION	MATERIAL WORKED	ANGLE OF USE	NUMBER OF STROKES
1	A 30 A 29	NO YES	0.8 2.1	4.7 4.6	1.3 1.7	25° 26°	0.10 0.09	IRREGULAR CONVEX	– –	CUTTING	MEAT	70 – 90° 70 – 90°	550 550
2	A 3 A 5	NO YES	34.9 25.3	5.3 5.6	4.4 3.9	87° 86°	0.35 0.25	IRREG./STRAIGHT IRREG./STRAIGHT	HAMMERST. ANTLER	SCRAPING	BONE	70 – 90° 50 – 70°	350 350
3	A 2 A 16	NO YES	24.0 16.3	5.5 5.5	4.1 3.1	74° 74°	0.30 0.12	CONVEX IRREG./CONVEX	HAMMERST. ANTLER	WHITTLING	ANTLER	– –	450 50
4	A 27 A 28	NO YES	1.1 1.5	2.9 2.9	1.8 1.6	10° 15°	0.02 0.09	CONVEX STRAIGHT	– –	CUTTING	MEAT	90° 90°	250 250
5	A 24 A 25	NO YES	0.7 0.4	3.6 2.8	1.3 0.9	30° 29°	0.11 0.10	CONVEX STRAIGHT	– –	SCRAPING	BIRCH	90° 90°	150 50
6	B 5 a B 5 b	NO YES	19.4 7.9	5.4 3.7	4.2 2.2	65° 65°	– –	CONCAVE/BURIN CONCAVE/BURIN	– –	GRAVING	PINE	70 – 90° 60 – 80°	350 50
7	B 3 b 2 B 3 b 1	NO YES	12.8 11.6	5.1 3.5	3.1 2.9	66° 75°	– –	STRAIGHT STRAIGHT	– –	SCRAPING	PINE	65° 65 – 70°	1000 1000
8	A 32 A 26	NO YES	1.1 0.5	4.0 3.3	1.0 1.3	22° 23°	0.09 0.05	STRAIGHT CONCAVE	– –	SAWING	BIRCH	90° 90°	250 150
9	A 4 A 11	NO YES	23.5 14.5	6.5 5.5	3.9 1.2	87° 76°	0.22 0.10	CONCAVE CONCAVE	ANTLER ANTLER	WHITTLING	BIRCH	65° 65°	250 150
10	C 4 C 3	NO YES	0.6 0.5	2.5 3.0	0.9 2.9	25° 26°	0.05 0.05	IRREGULAR STRAIGHT	– –	WHITTLING	PINE	20° 25°	250 150
11	A 1 A 10	NO YES	29.9 15.5	6.0 5.3	4.8 3.8	75° 72°	0.30 0.15	CONVEX IRREG./STRAIGHT	HAMMERST. HAMMERST.	WHITTLING	ANTLER	85° 85°	250 150
12	A 33 A 31	NO YES	2.7 0.7	4.8 4.5	1.5 1.2	33° 33°	1.10 0.10	STRAIGHT CONCAVE	– –	CUTTING	MEAT	70 – 90° 70 – 90°	550 550
13	A 37 A 36	NO YES	2.8 3.5	4.3 3.9	2.0 2.2	32° 32°	0.05 0.10	STRAIGHT CONCAVE	– –	CUTTING	MEAT	90° 90°	550 350
14	C 1 C 2	NO YES	0.7 0.4	2.8 3.3	0.9 0.8	32° 32°	0.10 0.09	CONVEX CONVEX	– –	SAWING	BIRCH	90° 90°	250 350
15	A 13 A 34	NO YES	4.3 3.2	4.8 4.0	1.8 1.7	48° 47°	0.12 1.80	CONCAVE CONCAVE	– –	SAWING	BIRCH	90° 90°	1000 550
16	A 35 A 22	NO YES	1.4 0.9	3.1 2.8	0.9 2.0	30° 31°	0.10 0.10	CONCAVE STRAIGHT	– –	SCRAPING	BIRCH	90° 90°	250 50.
17	A 20 A 38	NO YES	3.2 2.5	4.7 4.9	1.9 2.0	30° 28°	0.03 0.04	CONVEX CONCAVE	– –	SCRAPING	BIRCH	90° 90°	50 25
18	A 39 A 15	NO YES	10.9 15.9	4.8 5.7	2.7 3.9	77° 80°	0.21 0.30	IRREG./CONVEX IRREG./CONVEX	ANTLER ANTLER	SCRAPING	BONE	60° 60°	150 150
19	A 14 A 9	NO YES	25.4 20.4	6.7 5.4	3.3 3.6	85° 82°	0.30 0.30	CONVEX CONVEX	ANTLER ANTLER	SCRAPING	BONE	60° 50°	350 350
20	A 40 A 41	NO YES	20.1 17.2	5.3 5.1	3.2 2.9	37° 30°	0.30 0.30	POINTED POINTED	ANTLER ANTLER	DRILLING	BIRCH	90° 90°	50 50

Fig. I

Morphological and experimental data for the flake pairs

PLATE 1



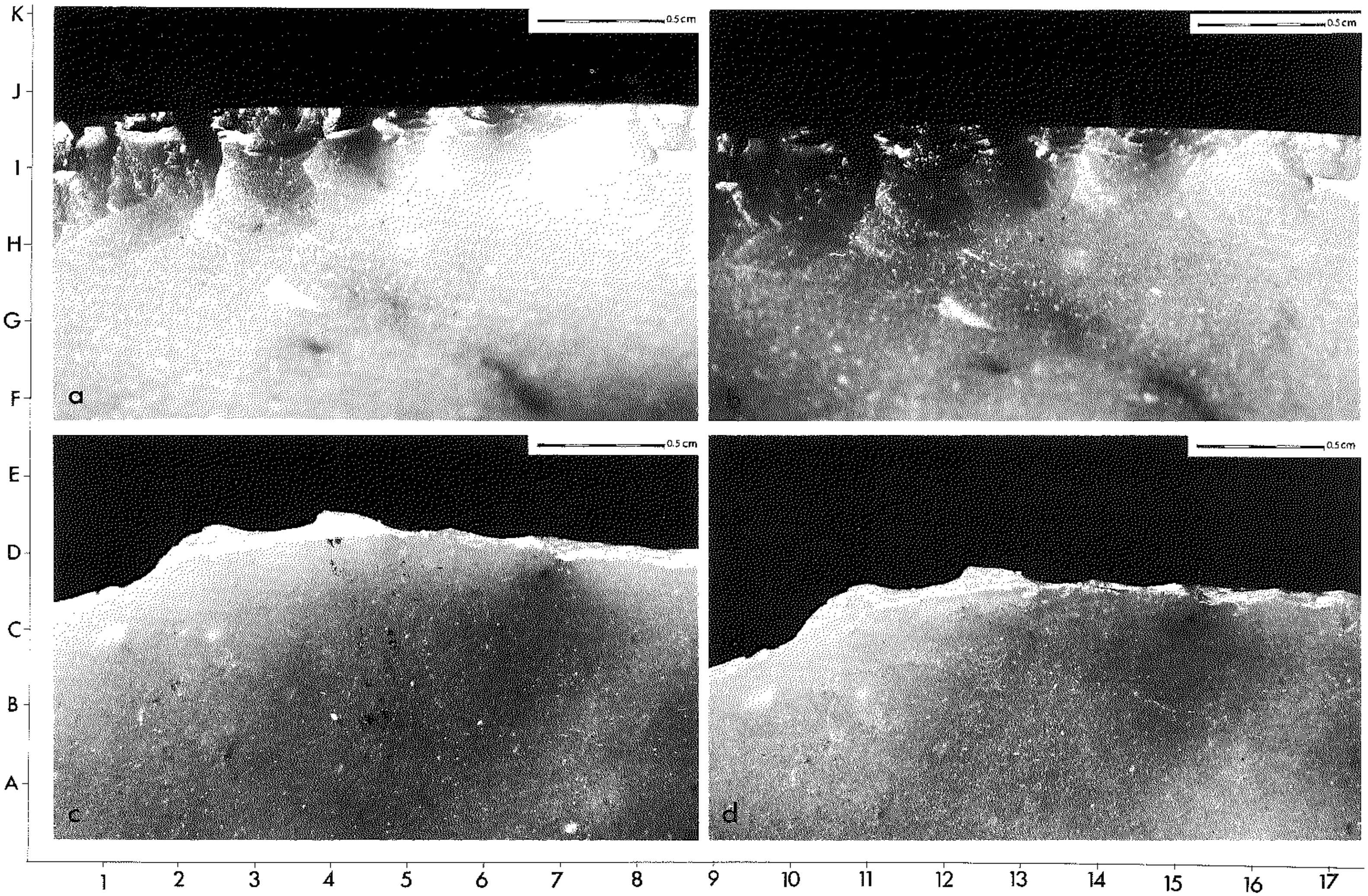
a. Experiment 3. Whittling elk antler with the unheated flake A2. The flake was held in a piece of leather to protect the hand. Plate 2 contains microphotographs of this edge

b. Experiment 5. Scraping fresh birch wood with the heat-treated flake A25. Compare pl. 5 for microphotographs of the edge of this flake

c. Experiment 6. Graving a fresh pine branch with the unheated flake B5a. The build-up of fibres at the end of the furrow is visible. See pl. 6 for microphotographs of the point of the tool

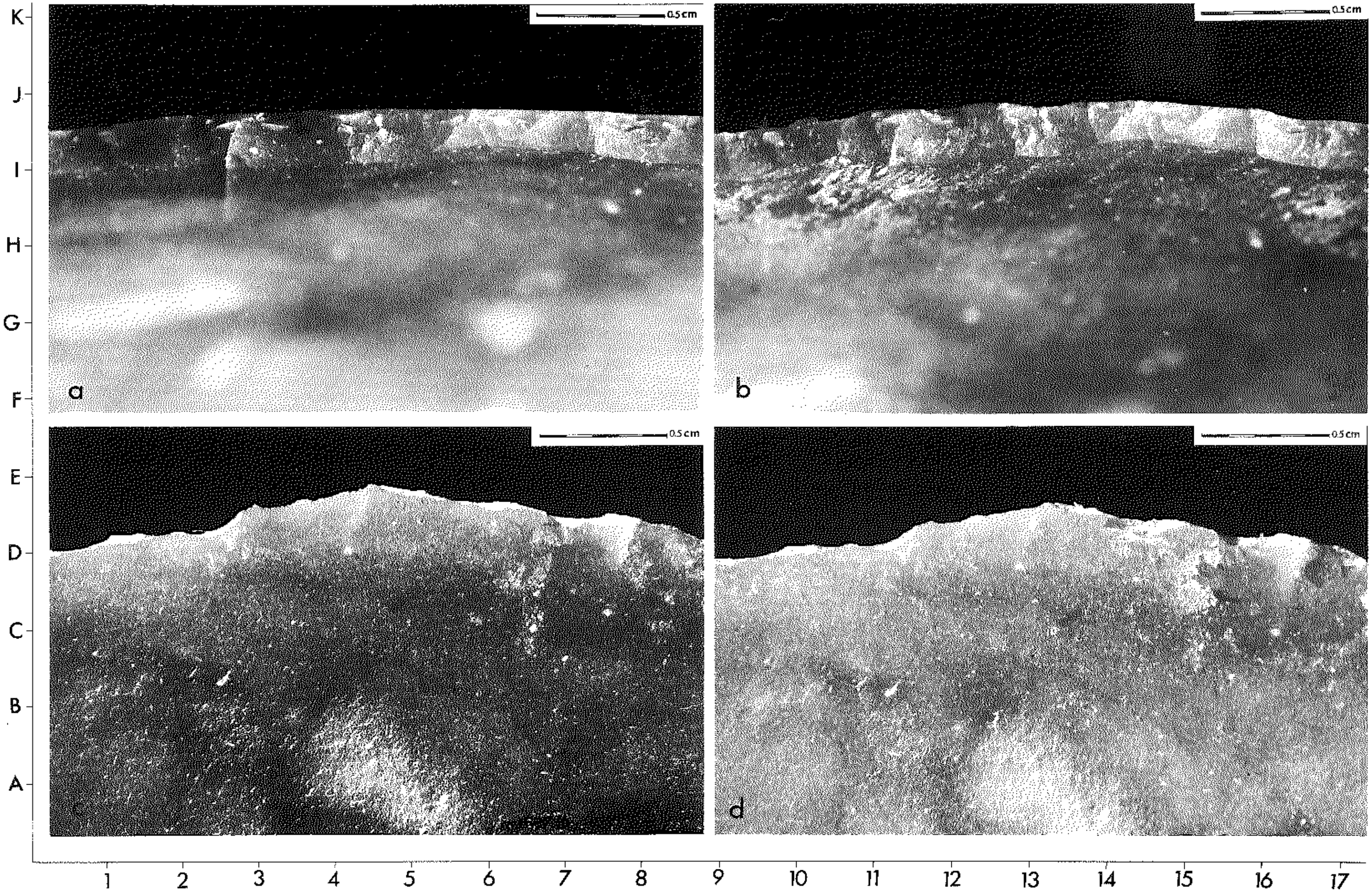
d. Experiment 12. Cutting fresh pork meat. There was little damage to the tool from this activity

PLATE 2



Experiment 3: Whittling elk antler. These photographs show the dorsal and ventral surfaces of the unheated flake A2 before use (a and c) and after 450 strokes (b and d). While it is difficult to locate use scars on the retouched dorsal edge, some nibbling is visible at I½:13–14. Wear is more evident on the ventral surface. Two feathered microscars are evident at C½:13 and C½:13½, while edge rounding is visible along most of the edge but especially at C½:14

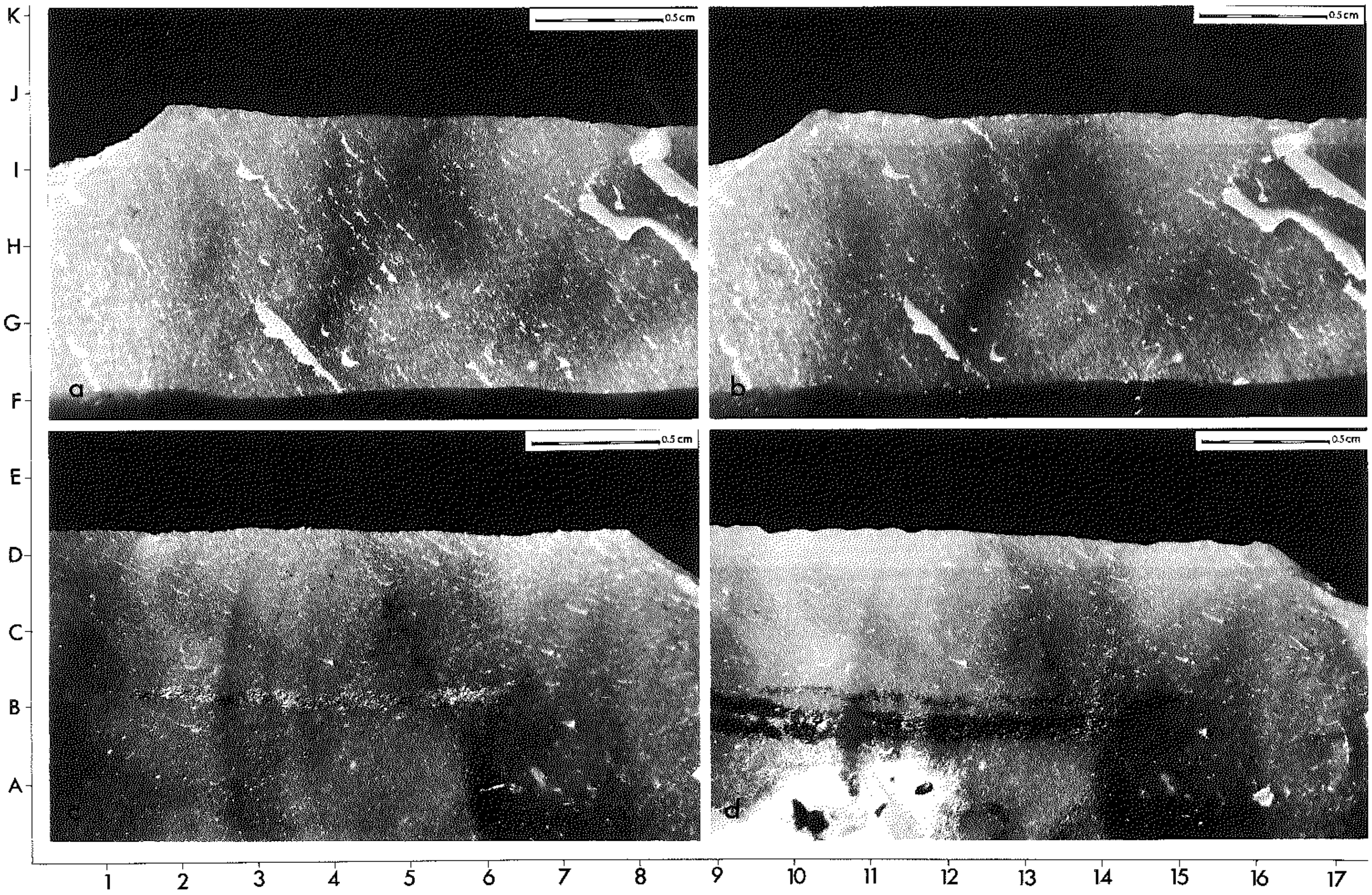
PLATE 3



Experiment 3: Whittling elk antler. These photographs show the dorsal (a and b) and ventral (c and d) surfaces of the heat-treated flake A16. Plates 3a and 3c show the flake before use; plates 3b and 3d show the same surfaces after only 50 strokes of use

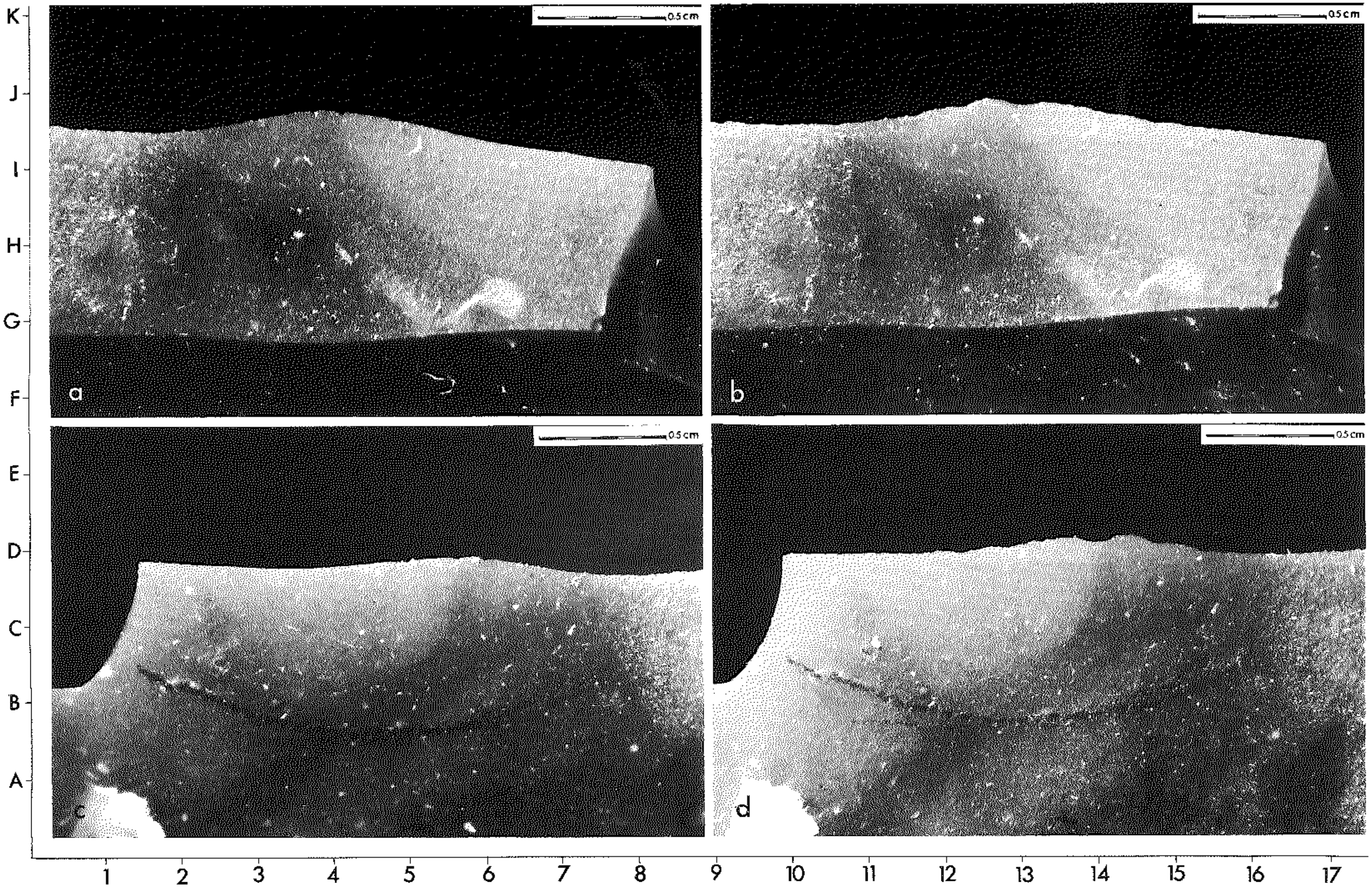
It is evident from these plates that wear is already heavier here after only 50 strokes than it was on the unheated flake after 450 strokes (pl. 2). Wear on the dorsal surface consists of step fractures at J:11½ and I½:13 and of nibbling at J:13½–15. Wear on the ventral surface is seen as step flaking at D:13–14½ and microflaking at D:17

PLATE 4



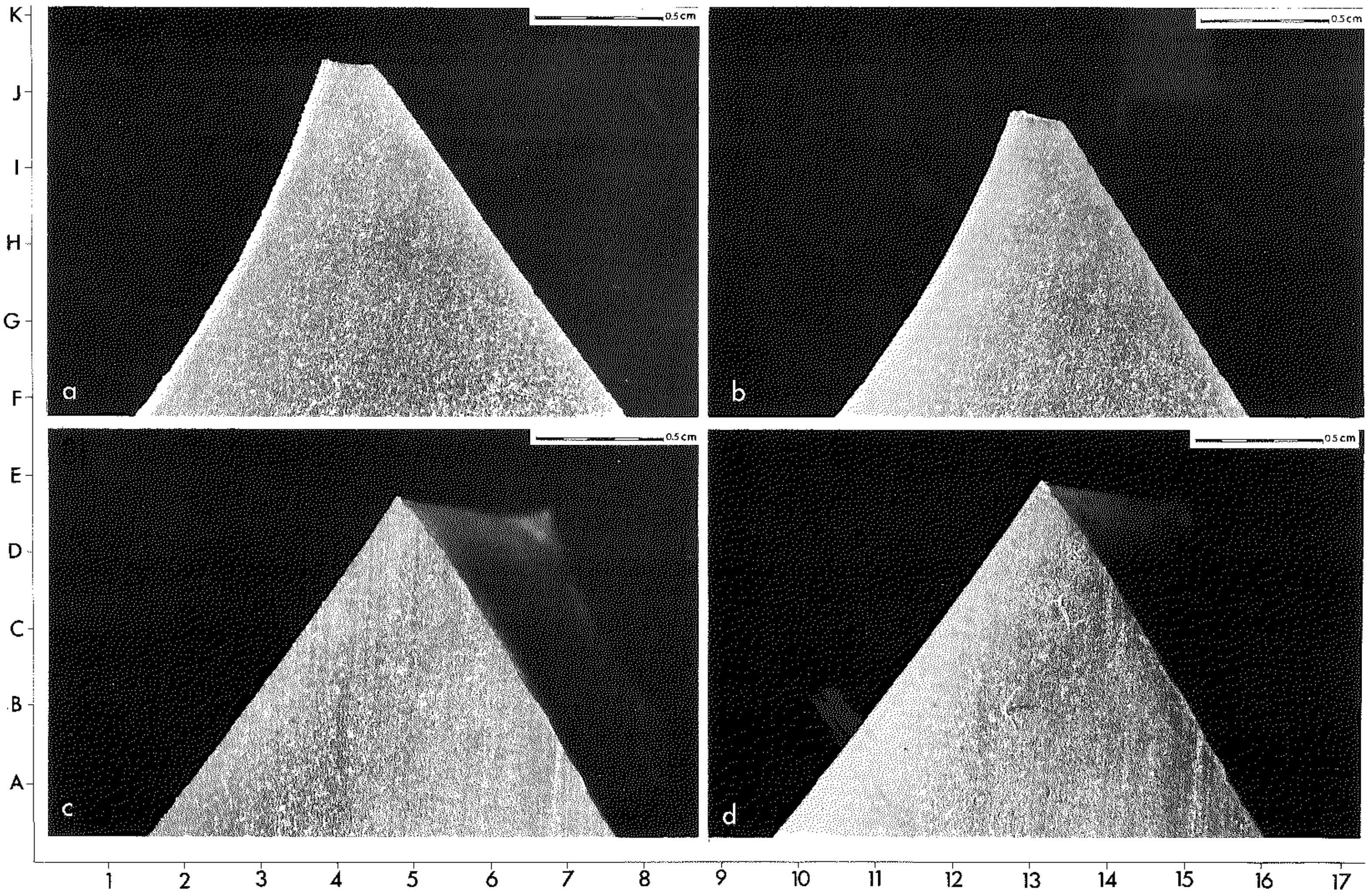
Experiment 5: Scraping fresh birch wood. The photographs show unheated flake A24 before use and after 150 strokes. Probably because of the thinness of the edge, damage was heavy and occurred quickly here. A general rounding of the edge is evident in both plates 4b and 4d. In addition, there are microflakes removed from the edge at I½:10½, I:10¾, I½:11¾, I½:14½, and I½:17 along the dorsal face, and at D:9¾, D:10¼, D:11, D:11½, D:14, D:14½ and D:15½ on the ventral side. Nibbling is evident along the dorsal surface on the edge at I½:12–14

PLATE 5



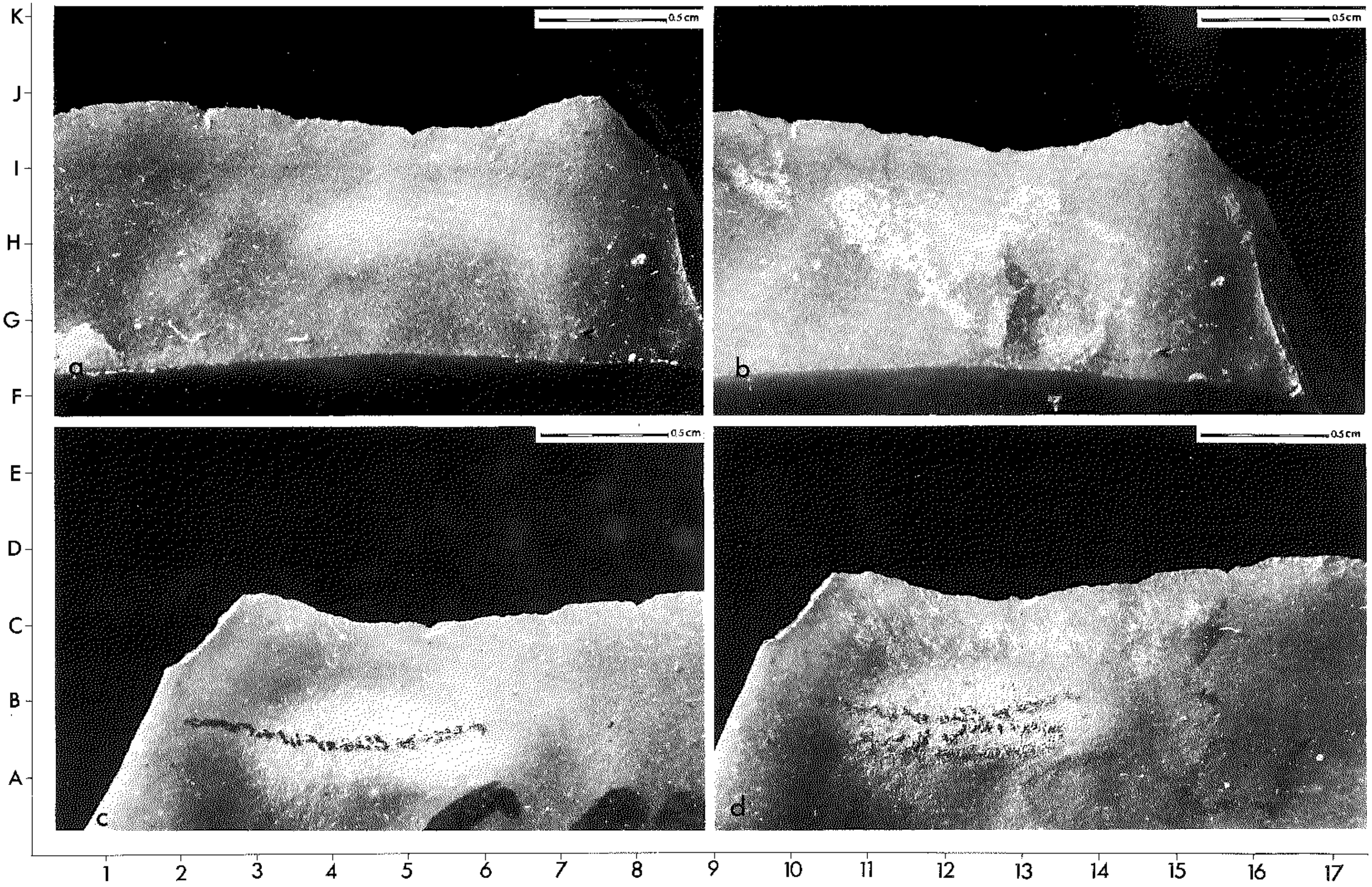
Experiment 5: Scraping fresh birch wood. The photographs show heat-treated flake A25 before use and after 50 strokes. Microflaking is visible at J:12, J:13, J:14½ and at D:12½, D:13¼, D:14, D:14½ and D:15½. Nibbling can be seen along most of the dorsal edge (5b)

PLATE 6



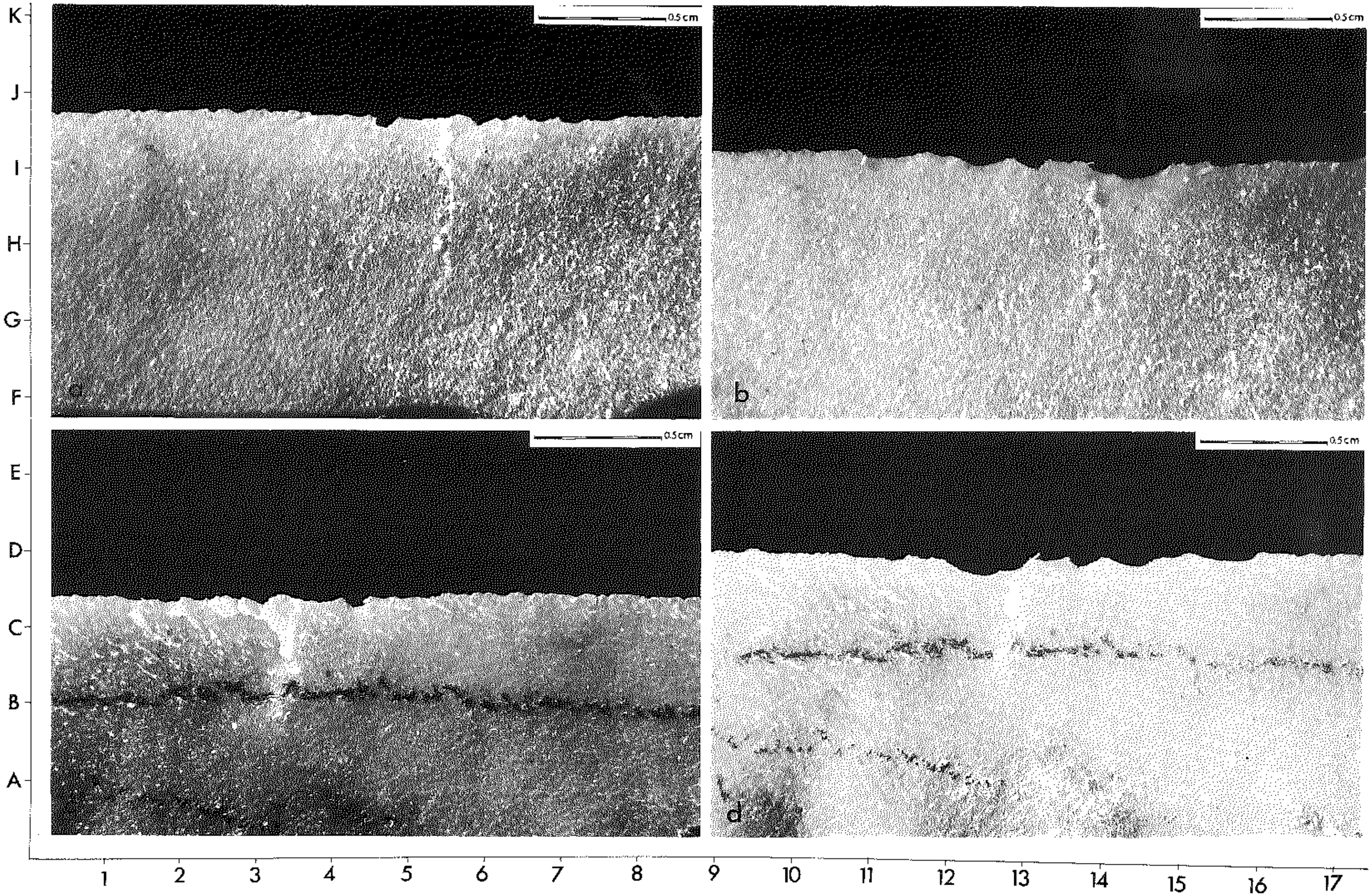
Experiment 6: Graving fresh pine wood. Plates 6a and 6b show the point of the unheated slab B5a before use and after 350 strokes. Photographs c and d show the heat-treated slab B5b before use and after 50 strokes. No wear is visible on the unheated slab after use, while a microflake has been detached from the point of the heated flake (E:13½). Striations from the geological saw are evident

PLATE 7



Experiment 10: Whittling fresh pine wood. Photographs 7a and 7c show the unheated flake C4 before use; photographs b and d show the same surfaces after whittling fresh pine wood for 250 strokes. Wear is evident as microflaking along the dorsal surface of the edge at I¼:11, I¼:13 and I½:14¾ and as nibbling on the ventral surface at C¾:16–17

PLATE 8



Experiment 10: Whittling fresh pine wood. Photographs 8a and 8c show the heat-treated flake C3 before use; photographs 8b and 8d show the same surfaces after 150 strokes. Wear is more severe here after 150 strokes than on the unheated flake after 250 strokes. Microflaking is evident at I:11, I:12¼, I:13, I:13¾, I:14 and at D:12½, D:13¾, D:14¼ and D:15½

materials were chosen from Keeley's appendix (1980, 179–82). It was sometimes necessary to substitute comparable materials available in Sweden for those tested by Keeley. In several cases the alternative action or material was chosen instead of the primary task listed by Keeley, in order to have as many flake pairs as possible performing the same experimental task. Figure 1 lists the experiments which were carried out, while a full description of the experiments can be found in the Appendix. The experimental series should be viewed as a pilot study, from which qualitative but not quantitative conclusions could be drawn. Since the morphlogy of the flake pairs determined which of the experimental tasks was appropriate, there is no particular significance as to which experiments were repeated more than once and which were done only once. It is of course not possible to formulate any general laws from such a small number of trials; rather the aim was to indicate trends which can be tested on other raw materials from different regions.

Prior to each experiment, the chosen edge on each of the pairs was examined once more at 16x and 40x magnifications and compared against the 'before' photographs. Occasionally a trial run with a similar flake was performed before the actual experiment, in order to establish the most effective working angle for the task. During each experiment, as many variables as possible were held constant and recorded for each experimental pair. These variables were: the raw material of the tool, the mechanical action, material worked, edge angle and edge morphology, the pressure applied, angle of attack, length of edge used, and number of strokes. Of course, if one wanted to reach true objectivity here, he could construct mechanical devices for holding and using the flakes so that the dynamic factors were truly equal for both flakes. But since only one operator (the author) used the flakes, and the members of the pairs were used directly after each other, it is doubtful that too much error crept in here. It was not thought necessary to haft the flakes, since this would have been a time-consuming process and most of the flakes were large enough to be held comfortably in the hand, often with the protection of a leather pad (pl. 1a). Of course if the aim had been to reconstruct prehistoric use, it would have been desirable to haft the tools.

During the course of the experiments each flake was washed in soapy water and the used edge was examined under the binocular microscope at 16x and 40x magnifications at regular intervals. The used edge was compared with the before photographs and the verbal descriptions of the tool edge before use, to note possible traces of use. Wear was recorded as the occurrence of certain categories of microflaking, as follows (cf. Ahler 1979, 316; Stafford 1977, 238) (arranged in order of severity):

Blunting or edge rounding: Rounding and smoothing of the edge and any protrusions (Ahler 1979, figs 4A and 5B; Brink 1978, 366) (pl. 2d).

Nibbling: Very slight microfracturing along a continuous stretch of edge (Seitzer 1979, 13) (pl. 5b).

Irregular flaking: Small feather terminated flakes (microflakes) removed from the edge at irregularly spaced intervals (Ahler 1979, 309) (pls 4b and 4d).

Step flaking: Removal of expanding flakes having a hinge termination (Ahler 1979, 309) (pl. 3b).

When wear traces were readily apparent, and/or when the flake was no longer performing effectively, its use was terminated so that it could be photographed (fig. 2). In some cases (Experiments 1, 7 and 12) wear was never apparent on the used edge, so that the experiment was terminated after an arbitrary number of strokes for both flakes, and photographs were taken. The flakes were handled with care and were stored separately in plastic bags to prevent accidental wear during handling. For the first ten experiments, the flakes were soaked in acetone for ten minutes after use to remove organic residues. The remaining ten pairs were simply scrubbed in soapy water before being photographed. The number of strokes at which wear first appeared should provide a measure of the relative speed of the formation of wear on the heated and unheated flakes

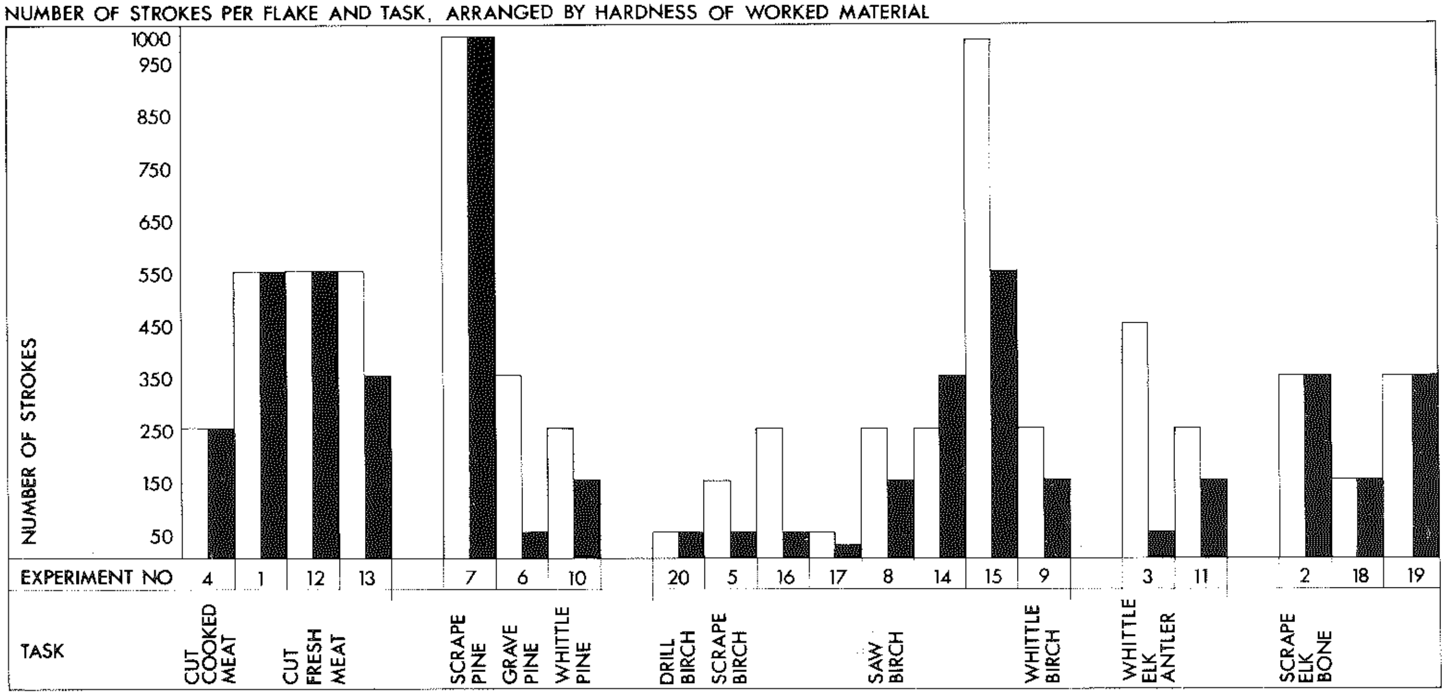


Fig. 2

The number of strokes per flake and task, arranged by the hardness of the worked material. Shaded histograms represent the heat-treated flake of each pair. Except in Experiment 14, the heat-treated flakes showed wear and/or a loss of efficiency at the same rate or earlier than their unheated flake counterparts

(Hypothesis 1) (fig. 2), while comparisons of the photographs of relevant edges before and after use should allow conclusions about wear intensity (Hypothesis 1), length of flakes removed (Hypothesis 2), frequency of hinge and step flaking (Hypothesis 3), and scar appearance (Hypothesis 4).

RESULTS

It is not possible at this stage to make generalizations on the basis of such a small number of experiments, especially since the effects of some of the mechanical actions (e.g. drilling) or worked materials (e.g. cooked meat) were only tested for a single pair of artefacts. The results were clearer in some cases than in others. The most effective means of reporting the results in detail would seem to be by discussing each of the hypotheses proposed at the outset.

Hypothesis 1. Because heat treatment reduces the hardness or toughness of a flake's edge, heat-treated flakes should wear more quickly and/or more intensely than untreated flakes (fig. 2; Table 1).

TABLE 1: TESTING HYPOTHESIS 1

Hardness class	*Worked material*	*Experiments support H_1*	*Experiments do not support H_1*	*Ambiguous results*
1	Meat	1, 4, 12, 13		
2	Pine	6, 10		7
3	Birch	5, 8, 9, 15, 16	14, 17, 20	
4	Antler	3, 11		
5	Bone	2, 18	19	

The experiments indicated that this hypothesis should be accepted, although with certain reservations. For purposes of examining the results, the materials worked can be arranged on a scale of hardness as follows: 1, meat; 2, pine; 3, birch; 4, antler; 5, bone. In the meat cutting experiments (nos 1, 4, 12 and 13) the heat-treated flakes wore both more quickly and more intensely than the raw flakes. Perhaps the clearest results were obtained in Experiment 13, in which the heated flake showed nibbling on its edge after only 50 strokes, while a comparable amount of wear did not appear on the unheated flake until it had been used for 250 strokes. At the conclusion of this experiment the heat-treated flake showed more wear after 350 strokes than was evident on the unheated flake after 550 strokes.

In use on pine wood (Experiments 6, 7 and 10), the results also supported the hypothesis. In Experiments 6 and 10 the heated flakes showed wear after 50 strokes, while the unheated flakes did not show a similar amount of wear until 250 or 350 strokes. The results for Experiment 7 were less convincing, as there was little wear on either flake even after use up to 1000 strokes. Plates 7 and 8 illustrate well the intensity of the wear which resulted from whittling pine wood; wear which arose sooner on the heat-treated than on the non-heat-treated flake.

For experiments with birch, which falls at the middle of the hardness scale for those materials tested here, the results were more ambiguous. In five of the experiments (5, 8, 9, 15 and 16) the results indicated the hypothesis should be supported, while for three (14, 17 and 20) they indicated just the opposite. The discrepancy cannot be due to the mechanical action, since, for example, a sawing action in Experiments 8 and 15 resulted in wear appearing on the heated flake after 50 strokes and on the unheated flake after 150, while for Experiment 14 sawing gave rise to wear on the non-heat-treated flake after 50 strokes though no wear appeared on the heat-treated edge until 350 strokes. At the conclusion of the experiment the unheated flake was more severely worn (after 250 strokes) than the heat-treated flake (after 350 strokes), which does not support the hypothesis.

The two experiments with elk antler (nos 3 and 11) indicated that heat treatment apparently also renders a flint edge more susceptible to wear when it is used on this hard material. In both cases heavy wear, indicated by step flaking, appeared after 50 strokes on the heat-treated flakes while the non-heat-treated flakes could be used for 450 and 150 strokes, respectively, before such wear was evident. 'Before' and 'after' photographs for the pair of flakes from Experiment 3 (pls 2 and 3) support this conclusion.

Finally, the three experiments (2, 18 and 19) on the hardest material, dried bone, yielded ambiguous results. The result of Experiment 2 supported the hypothesis, the heated flake showing heavy wear after 250 strokes and the unheated flake first after 350. For Experiment 18 the results were less certain, as both flakes appeared equally worn after 150 strokes. And Experiment 19 would seem to indicate a rejection of the hypothesis. Here, heavy wear appeared on the non-heat-treated flake after 50 strokes, while the heat-treated flake first exhibited similar wear at 150 strokes.

The ambiguity of these results may be due to a difficulty which plagues edge-wear analysis in general — namely, being able to distinguish between use-wear and manufacturing wear. Because bone is such a hard material, tools used to work bone must have a high edge angle (fig. 1), formed in this case by retouching the flake. It proved quite difficult to locate use-wear on this retouched edge as the edge was already full of retouch scars (e.g. pls 2a, 2b, 3a, 3b). This difficulty may account for the aberrant results here and is of course one of the pitfalls of the so-called low-power approach (e.g. Odell and Odell-Vereecken 1980) which examines primarily edge scarring rather than seeking material-specific polishes at higher magnifications. The reason for adopting the low-power approach here was the assumption that it is the edge damage, or scarring, arising during use which reduces the effectiveness of a tool. It is this change, rather than any microscopic polishes, which would have affected the user's relationship to his tools and his decision to heat-treat. From an edge-wear analyst's point of view, the study of the effects of heat treatment on the formation of edge damage (the low-power approach) is as important as the study of the effects of heat treatment on polish formation (the high-power approach: Keeley 1980), particularly when making reference collections of experimental tools.

Another reason for the ambiguity of the results reached may be that, although effort was made to hold edge morphology constant for each pair, minor variations near the edge may have altered the microfracturing characteristics of the pairs (Odell 1981, 207). However, this aspect is difficult to control for when knapped materials are used.

In summary, the results of these twenty experiments generally support the hypothesis that heat treatment renders flint flakes more susceptible to wear, so that such flakes wear more quickly and more severely than do flakes which have not been heated.

Hypothesis 2. Because heat treatment allows the removal of longer flakes, heat-treated flakes should show longer microflake removals from use than unheated flakes.

In order to determine the validity of this postulate, it was necessary to measure objectively the micro-flake removals from both heated and unheated flakes. This was done by simply measuring flake removals as they appeared in the scaled 'before' and 'after' photographs for each experiment (e.g. pls 4 and 5 or 7 and 8). In seven of the experiments (Table 2) both of the flakes showed at least one microflake scar after use. These scars were measured, and in cases where more than one flake scar was evident an average was calculated for that flake. As Table 2 shows, microflake removals from the heat-treated flakes are longer (as well as more numerous — cf. Hypothesis 1) than those from non-heat-treated flakes, so that this hypothesis also seems to be supported.

TABLE 2: LENGTH OF MICROFLAKES FROM USE (HYPOTHESIS 2)

	Unheated Tools		*Heated Tools*	
Experiment No.	*Length of Micro-flakes*	*Average length of Micro-flakes*	*Length of Micro-flakes*	*Average length of Micro-flakes*
			.80	
3	.27	.27	.40	.60
5	.06		.13	
	.06	.06	.10	.12
8	.20		.03	
	.13	.17	.03	.03
10	.10		.23	
	.47	.29	.37	
			.43	.34
13	.03	.03	.03	.03
15	.23	.23	.23	
			.07	.15
16	.07	.07	.33	
			.20	
			.07	
			.07	
			.13	.16
Average length of microflakes from use		.16 mm		.20 mm

Hypothesis 3. Because heat treatment reduces step and hinge fractures, such terminations should be fewer and should form more slowly on heat-treated than on non-heat-treated flakes (Table 3).

Following Hayden (1979, 133–34), a step fracture is defined as a 'flake scar that terminates abruptly in a right-angle break', while a 'hinge facture meets the surface at a steep angle or approximately right-angles to the longitudinal axis'. Such fractures were not a common occurrence in this experimental series. When they did occur it was usually on the retouched edges and they were therefore hard to distinguish from manufacturing wear (cf. p. 8 above). It proved difficult to quantify the number of step or hinge terminations on the flakes, so that a criterion of presence/absence was used instead. For the six experiments in which step or hinge flaking was observed on at least one of the flakes, the results suggest that the hypothesis should be rejected. In two cases (Experiments 2 and 18, bone working) step flaking arose at the same rate on both raw and heated flakes. For two of the experiments with antler working (nos 3 and 11), step flaking arose more slowly on the unheated flakes that on the heated flakes. In only two experiments (7 and 19) did the results suggest that the hypothesis was true. For Experiment 7 (scraping pine wood) the unheated flake showed step terminations after 250 strokes, while by the conclusion of the experiment (1000 strokes) such scars still had not appeared on the heat-treated flake. In Experiment 19 (scraping bone) hinge and step fractures arose on the raw flake by 50 strokes, while they were not present on the heat-treated flake until 150 strokes. However, with four of the six experiments yielding negative results, the hypothesis must be rejected, or at least modified.

TABLE 3: TESTING HYPOTHESIS 3

Experiment number	*Worked material*	*Number of strokes at which step terminations appear*		*H_3 supported?*
		Non heat-treated	*Heat-treated*	
2	Bone	50	50	No
3	Antler	150	50	No
7	Pine	250	—	Yes
11	Antler	150	50	No
18	Bone	150	150	No
19	Bone	50	150	Yes

These results agree with those reached by Bleed and Meier in a recent study. They too discovered that heat treatment increased the tendency of flakes to terminate in hinges. They found that on the flint tiles they heated to 400° C, hinge flakes outnumbered feather terminations by five to one (Bleed and Meier 1980, 505).

The hypothesis is based on the behaviour of flint during manufacturing processes, and it may be that the stresses which give rise to hinge and step flaking during manufacture are not the same as those which give rise to such fracture terminations during use. The results here suggest that heat treatment may be particularly undesirable for tools intended for use on hard materials, as the more rapid formation of step flaking would increase the tool's edge angle, thereby strengthening, but at the same time dulling, the working edge (cf. Odell 1982, 26).

Hypothesis 4. Because heat treatment causes subsequent flake scar surfaces to be shiny, the scars on heat-treated tools from flakes removed during use should be shiny.

This hypothesis was substantiated by the experiments, although the shiny scars observed under the microscope did not reproduce well in the photographs (but cf. pl. 5b from Experiment 5). Glossy microflake scars could be observed on six of the experimental heat-treated flakes (Experiments 3, 6, 9, 10, 15 and 20), while none of the microflake scars present on the unheated flints was shiny.

CONCLUSIONS

On the basis of these experiments, the following conclusions can be drawn:

1. Heat treatment makes flint more susceptible to wear during use, so that heat-treated tools wear more quickly and with more severity than tools which have not been heated.

2. When used in the same fashion and on the same materials, heat-treated flakes will show longer microflake removals from use than will non-heat-treated flakes.

3. Contrary to what is true during the manufacture of flint tools, *use* of such tools yields more step and hinge flake terminations when the tools are made from heat-treated than from unheated flint.

4. Flake scars from microflaking due to use will have a shiny surface on flints which have been heat-treated, while such surfaces will be matt on unheated materials.

It is important that the edge-wear specialist be aware of the changes in the severity and appearance of wear which heat treatment can cause on tools from archaeological collections. This is especially true when the researcher is building up a reference collection of experimentally used tools for comparisons with aboriginal specimens, since, as shown here, heat treatment can significantly alter the physical properties of a raw material with respect to subsequent edge damage. Further, the discovery of more numerous step terminations than expected, or longer flake removals, or shiny use scars, may all be indications to the edge-wear specialist that the tools he is studying have been subjected to heat treatment by their makers, and tests should be undertaken to determine if this is so before further edge-wear analysis is carried out on the collection.

The results of the experiments also yield insight into aboriginal man's knowledge of his raw materials. A better understanding of the characteristics of available raw materials enables us to judge their strengths and weaknesses more as the aborigine might have judged them. The knowledge that a heat-treated tool will wear more quickly and more severely than one which has not been heated may, for instance, be an explanation for a group's decision not to apply heat treatment to certain classes of tools, even though the technique was known to them.

Further experiments, using other raw materials and other activities, are of course required before the above conclusions can be said to have more general validity. A program of experiments in which the high-power approach is applied would be beneficial in exploring the interesting question of the effects of heat treatment on polish formation (Andersen 1980) and the relationship between heat treatment and phenomena such as sickle gloss and other glosses (Kamminga 1979; Masson *et al.* 1981; Olausson and Larsson 1982).

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APPENDIX: DESCRIPTION OF THE EXPERIMENTS (fig. 1)

Experiment 1. Cutting fresh pork (pl. 1d). Unidirectional cutting strokes, according to Keeley (1980, fig. 3i), were used to slice through the skin, tendons, and meat of fresh pig's feet. The meat offered little resistance to the sharp edge of the flake, but the tough skin and tendons were somewhat harder to cut through. Care was taken not to let the flake come in contact with any bone, as this would presumably have resulted in heavier wear.

2. Scraping cooked elk bone. Unidirectional scraping, according to Keely (1980, fig. 3c), was applied to an elk (*Alces alces*) metatarsal. The bone had been cooked for several hours to soften fleshy parts, which were then removed. The bone had been stored at room temperature for about ten months, so that it was quite dried out and hard. A scraping angle of about 70° to the bone proved to be the most effective here. Although Keeley notes that working dry bone with flint tools is difficult (1980, 44), it was found that sufficient pressure removed a fine 'bone dust' with every stroke of the tool.

3. Whittling soaked elk antler. Elk antler, soaked in water for eight days to soften it, was subjected to unidirectional whittling as illustrated in Keeley (1980, fig. 3a). The hard shiny surface was difficult to penetrate and created heavy wear on the flakes.

4. Cutting cooked pork meat. A piece of fatty, boneless pork meat was roasted for one hour. The flakes were used in unidirectional strokes as in Experiment 1. The meat was kept on a soft cardboard tray so there would be no accidental wear if the tool slipped and hit the support (Keeley and Newcomer 1977, 49). The outer surface and the rind of the meat were crusty and offered much more resistance to the flakes than the inner fatty parts.

5. Scraping fresh birch (pl. 1b). Unidirectional scraping strokes, as in Experiment 2, were used to scrape a freshly cut birch (*Betula verrucosa*) branch. Scraping was performed parallel to the grain of the wood, beginning at the bark and working inwards. Small knots in the wood offered resistance to the flakes. Fresh wood rather than seasoned wood was used in this and other experiments, in consideration of Keeley's observation that seasoned wood is very hard to work with unground flint edges (1980, 69).

6. Graving fresh pine (pl. 1c). A freshly cut pine branch (*Picea albies*) *c.* 5.5 cm in diameter was worked with two of the sawed slabs having burin-like edges. Graving was unidirectional and parallel to the wood grain, with the *biseau* moving parallel to the direction of the stroke. Strokes began at the bark, and the tools were very effective. They quickly engraved such a deep furrow that it was necessary to begin a fresh furrow. A build-up of fibres at the end of the furrow hampered long strokes.

7. Scraping fresh pine. The same pine branch as in Experiment 6 was subjected to unidirectional scraping. The flint flakes proved very effective in working the soft pine wood.

8. Sawing fresh birch. Bidirectional sawing strokes, as illustrated by Keeley (1980, fig. 3i), were used to saw a fresh birch branch *c.* 8 cm in diameter. Each bidirectional sawing motion was counted as two strokes. Sawing was begun at the bark, perpendicular to the grain of the wood. In spite of their delicate appearance, the thin flakes used for this task proved quite effective and durable, as long as strokes were kept at a constant 90° angle and the tool was not twisted in the furrow.

9. Whittling fresh birch. The same birch branch was subjected to whittling, as shown in Keeley (1980, fig. 3a).

10. Whittling fresh pine. Unidirectional whittling strokes were applied to a fresh pine branch.

11–19. As above.

20. Drilling fresh birch. Unidirectional drilling, as in Keeley (1980, fig. 3f), was applied to a fresh birch branch. One complete revolution equalled one stroke.

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