Chapter 3
Experiments in Fracture Patterns and Impact Velocity with Replica Hunting Weapons from Japan

Katsuhiro Sano, Yoshitaka Denda, and Masayoshi Oba

Abstract Recent anthropological and archaeological studies in western Eurasia indicate that long-range projectile hunting was innovated by modern humans, and that complex projectile technology, such as using spearthrowers or bows (Shea and Sisk 2010), was an important component of behavioral modernity. The morphometric analysis of stone tips, including tip cross-sectional area (TCSA) and tip cross-sectional perimeter (TCSP), may facilitate suggestions for an optimum delivery method of stone tips as hunting weaponry. However, the suggested method does not always coincide with the true functions of the stone tips. Thus, this study developed a projectile experiment project to confirm additional indicators for identifying the delivery methods of prehistoric hunting armatures and to detect the emergence of spearthrower darts and bows and arrows in East Asia. Furthermore, macroscopic and microscopic analyses of the experimental specimens reveal a correlation between both the formation patterns of impact fractures as well as microscopic linear impact traces (MLIT) and impact velocities. This paper presents results of the projectile experiments, which provide indices to examine spearthrower darts and arrowheads in archaeological assemblages.

Keywords Delivery modes • Long-range projectiles • Projectile experiments • Impact fractures • MLIT • Trapezoids • Japanese Paleolithic

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Introduction

The earliest clear evidence of hunting weaponry is wooden spears discovered at a Lower Paleolithic site in Schöningen, Germany. The objects are dated at c. 400 ka (Thieme 1996, 1997) or c. 310 ka (Jöris and Baales 2003), and the new U/Th data ranging from 348 to 280 ka (Urban et al. 2011) supports the latter. Although O'Brien (1981) concluded an experimental study by claiming that an Acheulian handaxe was used as a projectile weapon, the hypothesis was challenged because of the lack of impact damage on handaxes (Whittaker and McCall 2001). As the weight and position of maximum thickness of the Schöningen spears are similar to those of modern athletic javelins, Thieme (2005) suggested that the spears were utilized as hand-casting spears; however, this remains debatable. The Middle Paleolithic humans probably began using stone-tipped weapons, such as Levallois points (Boëda et al. 1999, 2008), which increased impact energy. However, their hunting included frequent close encounters with prey, based on the observation of scars from hunting wounds on several Neanderthal fossils (Berger and Trinkaus 1995). In addition, while marked asymmetry humeral retroversion of anatomically modern humans suggests habitual throwing, investigations of Neanderthal skeletons demonstrate a lack of regular throwing (Rhodes and Churchill 2009). This anthropological evidence suggests that modern humans would have been the first to innovate long-range projectile hunting.

On the other hand, the direct archaeological evidence for true long-range projectile hunting using spearthrowers or bows (Churchill 1993) emerged not from the initial Upper Paleolithic, but from the middle Upper Paleolithic period in Europe, as evidenced by the spearthrower hook discovered at the Solutrean layer in Combe Saunière, France, which was dated at between 19 and 17 ^{14}C kBP (Geneste and Plisson 1986; Cattelain 1989). However, studies on the tip cross-sectional area (TCSA) of hunting armatures indicated that stone tips, including darts propelled by spearthrowers,

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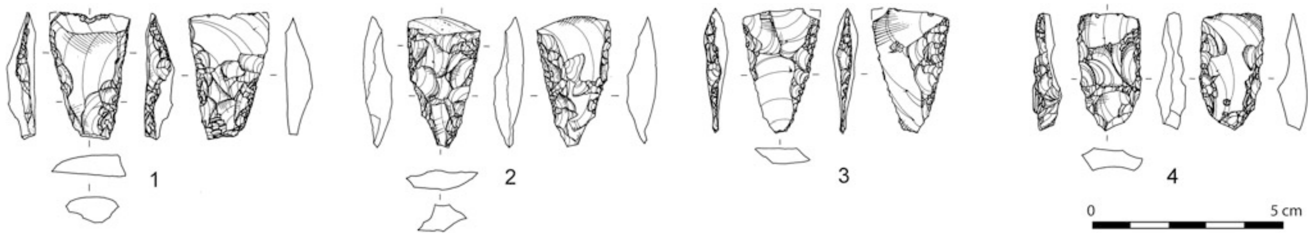

Fig. 3.1 Trapezoids from Layer Vb at the Hinatabayashi B site in Japan dated at between 31.4 and 28.2 ^{14}C kBP (after Tani 2000)

may have appeared after 50 ka in western Eurasia, which coincides with when modern humans expanded out of Africa and to the Old World (Shea 2006; Shea and Sisk 2010). Moreover, a tip cross-sectional perimeter (TCSP) analysis of several samples of African Middle Stone Age points, such as bifacial points from Porc Epic and Aterian tanged points from Aoulef, also suggested that they could have been used as spearthrower darts (Sisk and Shea 2011).

The TCSA and TCSP are practical indicators for suggesting the capability of hunting weaponry and for assuming the potential projectile systems. Nevertheless, the TCSA and TCSP values are not absolute proxies for identifying projectile delivery methods and for reconstructing actual functions (see Newman and Moore 2013; Clarkson 2016), and other indicators are therefore required to accurately detect the types of projectile systems for which the stone tips were actually employed. Thus, this study developed a projectile experiment project to establish criteria for identifying the employed hunting methods through formation patterns of impact fractures and MLIT related to delivery modes such as spear-thrusting, javelin-throwing, as well as the use of spearthrower darts and bows and arrows.

Projectile experiments regarding impact fracture formation patterns have been conducted to identify hunting weapons (e.g., Barton and Bergman 1982; Moss and Newcomer 1982; Bergman and Newcomer 1983; Fischer et al. 1984; Shea 1988; Midoshima 1991, 1996; Geneste and Plisson 1993; Caspar and De Bie 1996), and in recent decades, a variety of projectile experiments have been performed to understand prehistoric hunting technologies (Shea et al. 2001; Lombard et al. 2004; Lombard and Pargeter 2008; Sisk and Shea 2009; Yaroshevich et al. 2010; Pétillon et al. 2011; Sano and Oba 2015). One author (K. Sano) compared the formation patterns of the "diagnostic impact fractures" (DIF) with accidental fractures, which can occur during lithic production and syn-/post-depositional processes, and presented more reliable DIF exclusive to the hunting context (Sano 2009).

MLIT are another distinctive impact scar; they are microscopically observable at magnifications from 50× to 500× (Moss and Newcomer 1982; Fischer et al. 1984; Geneste and Plisson 1993; Caspar and De Bie 1996; Crombé et al. 2001; Yaroshevich et al. 2010; Sano and Oba 2015). MLIT are comprised of clusters of linear polishes running parallel to one another, which give them their striped appearance. MLIT are most likely formed due to contact with bone or fragments of stone tips (Moss and Newcomer 1982; Fischer et al. 1984). Since little is known regarding the formation patterns of MLIT, further experiments are required to better understand the formation mechanics.

If the hypothesis that complex projectile technology appeared after 50 ka, when *Homo sapiens* expanded to the Old World (Shea and Sisk 2010), is true, there must also be evidence of the use of spearthrowers or bows at early Upper Paleolithic sites in East Asia. This project performs projectile experiments with representative hunting armatures from the Japanese islands, including trapezoids, backed points, leaf-shaped points, and antler points in which microblades have been inserted, and reveals when the use of spearthrower darts and bows and arrows began in East Asia. This paper presents the results of the experiments centered on trapezoids (Fig. 3.1) that emerged between c. 38 and c. 30 cal kBP in early Upper Paleolithic Japan (Kudo and Kumon 2012), and some of which were probably hunting armatures (Yamaoka 2012). Furthermore, we discuss the possibility of reconstructing hunting delivery modes on the basis of the formation patterns of impact fractures and MLIT.

Methods

A calibrated crossbow was employed to accurately control loading conditions according to the estimated impact velocities of throwing, spearthrowers, and bows and arrows (Fig. 3.2). For thrusting, a realistic experiment was conducted because the kinematic mechanics of thrusting is difficult to reconstruct using the crossbow; one male student (1.81 m tall and weighing 76 kg) performed the required actions.

Ethnographic data indicate that spearthrowers enabled hunting at a distance of over 30 m (Churchill 1993; Stodiek 1993; Cattelain 1997). However, the effective hunting range of spearthrowers was 15–30 m (Stodiek 1993). Furthermore,

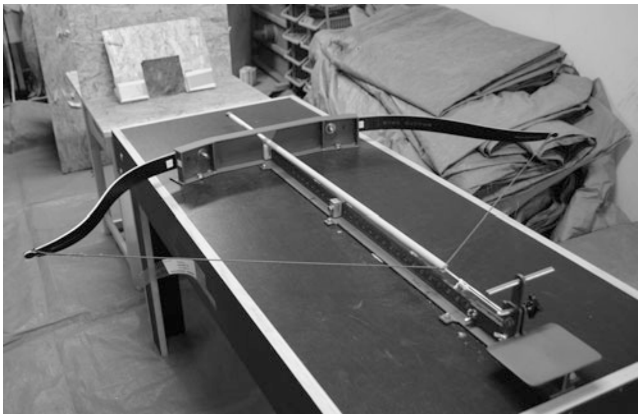

Fig. 3.2 Crossbow used for the projectile experiments

Fig. 3.3 Example of hafting a stone tip to a foreshaft

ethnographic and experimental studies indicated that its accuracy decreased between 20 and 30 m (Stodiek 1993; Cattelain 1997). The bow and arrow was effective between 20 and 30 m in the majority of cases and the "successful shots with high-performance equipment are taken at distances from 10 to 20 m on average" (Cattelain 1997). Based on these findings, we can estimate that the most effective and average range was approximately 20 m for both spearthrowers and bows. Stodiek (1993) recorded the velocities of spearthrower darts and bows and arrows using high-speed film and reported that the average velocity of spearthrowers from 20 m was 21.7 m/s while that of bows was 31.4 m/s. Regarding the throwing hunting, as there was no available data on the decline rate of the velocity according to distance, we employed the average velocity of 17.8 m/s presented by Hughes (1998). Thus, we calibrated the crossbow to shoot spears at impact velocities of 31.4 m/s for bows, 21.7 m/s for spearthrowers, and 17.8 m/s for throwing, with ±1.0 m/s deviation (Table 3.1).

Table 3.1 Velocities at a range of 20 m by bows and spearthrowers and the average throwing velocity

Delivery modes	Velocity (m/s)	Range (m)	References
Bow and arrow	31.4	20	Stodiek (1993)
Spearthrower dart	21.7	20	Stodiek (1993)
Throwing spear	17.8	–	Hughes (1998)

The lithic tips were first hafted to wooden foreshafts using glue (Fig. 3.3) before being fastened to the main shafts. A skillful knapper (M. Oba) produced lithic replicas of trapezoids made on siliceous shale from the Yamagata Prefecture in Japan. This shale was a high-quality raw material most frequently recovered at Paleolithic sites in the Tohoku region, which we are currently investigating. Forty trapezoid specimens were prepared for the experiments (Fig. 3.4), 10 of which were used for the experiments of thrusting, throwing, spearthrowers, and bows. A joint made from stainless steel, used to connect the foreshafts with the main shaft, weighed 16.8 g, and the wooden main shaft weighed 120.0 g. Each specimen was shot only once at an undamaged target assembled from deer hide, pig meat, and cattle scapulae. The target was set at a distance of 1.5 m from the crossbow to ensure that the impact and initial velocities were almost identical. The specimens were then macroscopically and microscopically observed. For the microscopic analysis, we utilized a digital microscope (KEYENCE VHX-1000) at magnifications from 100× to 500×.

Before the experiments, we examined whether the morphological variability of the trapezoid replicas can influence impact fracture formation patterns. The measured attributes of the trapezoid specimens, including length/width, length/thickness, TCSA, TCSP, weights, average angle at three parts of edges, a/b, c^l/b^l, and c^r/d^r (Fig. 3.5), are displayed in Table 3.2. The statistical significance of the difference among the attributes for thrusting, throwing, spearthrowers, and bows was assessed by using the

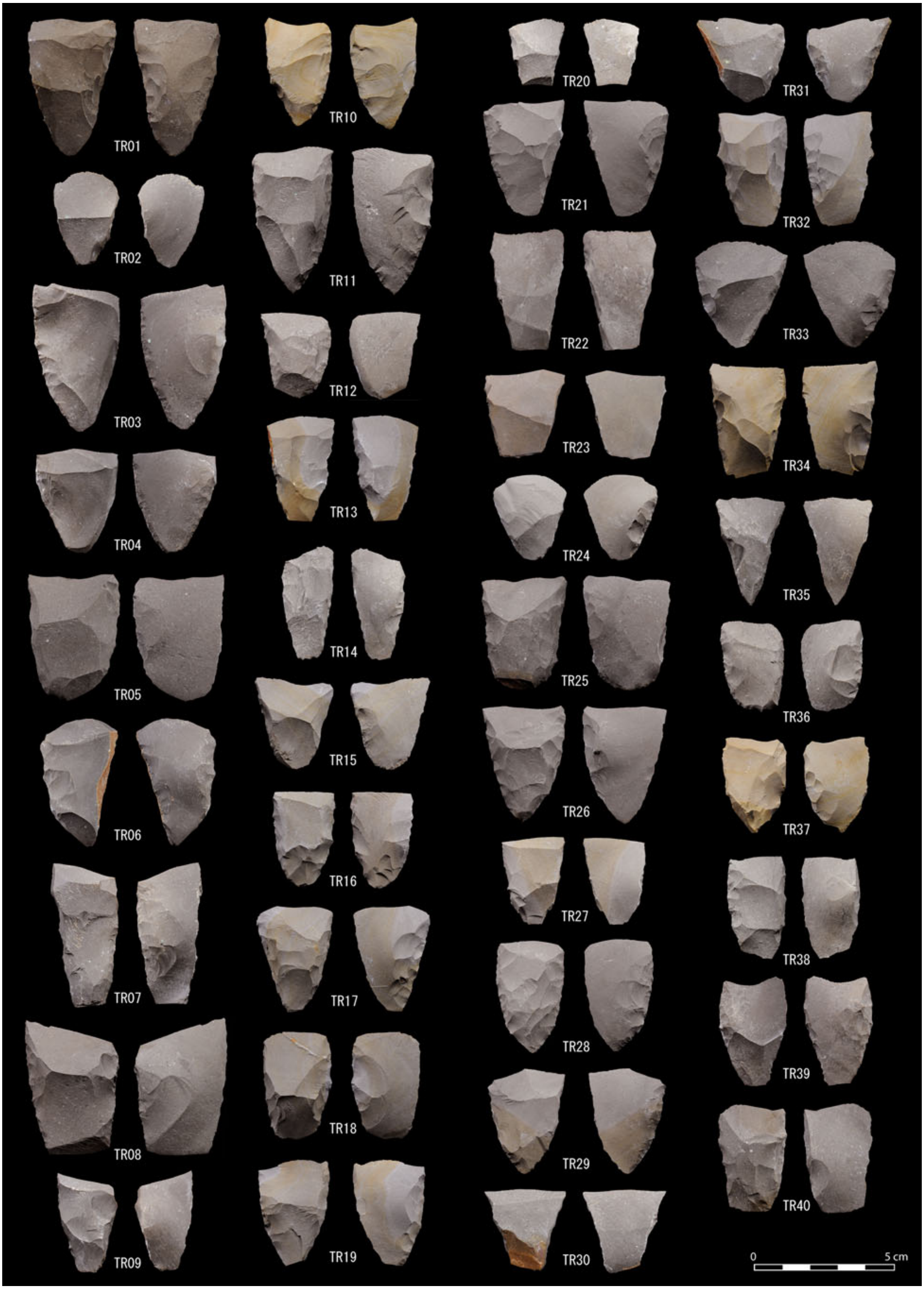

Fig. 3.4 Lithic replicas of trapezoids used for the experiments

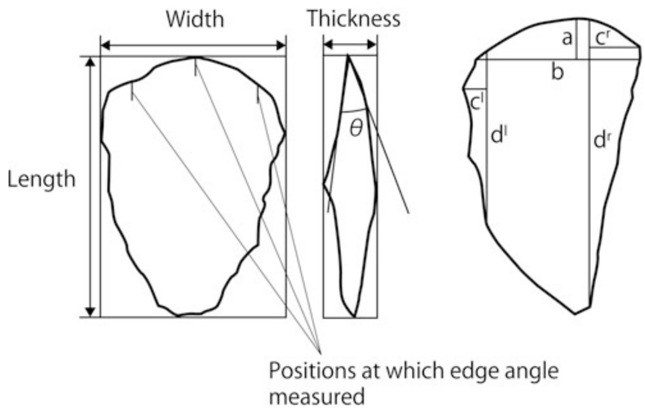

Fig. 3.5 Measured attributes for examining morphological variability among the experimental specimens. *b* is the maximum width of the distal portion. *a* is the distance from the distal end to the line *b*. d^l is the distance between the left end of the base and the point of contact between the line from the left base end parallel to the long axe and the outline. c^l is the distance from the point of the left maximum curvature to d^l. d^r is a distance between the right end of the base and the point of contact between the line from the right base end parallel to the long axe and the outline. c^r is the distance from the point of the right maximum curvature to d^r

Steel-Dwass multiple comparison test at a significance level of 0.05. As all the values were less than the critical value of 2.569 (Table 3.3), the null hypothesis that there were no significant differences between the specimens was not rejected. Hence, we cannot conclude that the morphological variance was sufficiently significant to influence the fracture formation patterns.

Furthermore, the TCSA and TCSP values of the trapezoid replicas were compared with those of North American ethnographic dart tips and arrowheads presented by Thomas (1978) and Shott (1997) (Fig. 3.6). The size and morphology of the replicas were based on the trapezoids unearthed at the Hinatabayashi B site in Japan. Both the TCSA and TCSP values of the replicas were larger than those of the ethnographic dart tips and arrowheads. However, because of the trapezoidal morphology, most trapezoids have their maximum width at the tip. Therefore, the TCSA and TCSP values of the trapezoids should not be directly compared to those of the ethnographic dart tips and arrowheads.

Table 3.2 Attributes of the trapezoid replicas

		L/W	L/Th	Weight (g)	Angle	a/b	c^l/d^l	c^r/d^r	TCSA	TCSP
Thrusting	Mean	1.59	4.97	11.0	43.9	0.15	0.20	0.17	132.1	59.3
	Std dev.	0.26	1.42	5.11	8.78	0.16	0.06	0.08	47.5	8.98
	Min.	1.25	3.64	4.56	28.7	−0.12	0.08	0.05	87.3	87.3
	Max	2.20	8.51	18.1	55.3	0.39	0.30	0.29	210.6	210.6
Throwing	Mean	1.62	3.89	8.15	42.8	0.13	0.19	0.19	116.8	51.2
	Std dev.	0.38	0.56	3.48	7.36	0.11	0.06	0.06	39.4	11.36
	Min.	1.15	3.10	2.52	35.0	−0.11	0.12	0.10	28.7	23.2
	Max	2.39	4.92	16.1	54.7	0.35	0.27	0.28	167.3	62.6
Spearthrower	Mean	1.34	4.50	8.35	41.7	0.11	0.21	0.19	118.4	58.0
	Std dev.	0.21	0.98	3.22	5.89	0.08	0.09	0.08	36.8	5.76
	Min.	1.01	3.19	4.37	33.3	0.04	0.12	0.06	78.3	47.5
	Max	1.66	6.63	12.96	50.3	0.26	0.36	0.29	197.1	65.7
Bow	Mean	1.45	4.21	7.47	37.7	0.05	0.19	0.15	115.7	55.1
	Std dev.	0.24	0.63	2.15	7.11	0.12	0.08	0.14	22.2	7.15
	Min.	0.85	3.55	4.86	30.0	−0.14	0.09	−0.06	91.4	45.5
	Max	1.75	5.24	10.8	50.7	0.18	0.35	0.40	151.4	67.3

Table 3.3 Multiple comparisons of attributes of the trapezoid replicas using Steel-Dwass test. Critical value = 2.569

		L/W	L/Th	Weight	Angle	a/b	c^l/d^l	c^r/d^r	TCSA	TCSP
Thrusting	Throwing	0.076	2.343	1.172	0.378	0.680	0.454	0.680	0.151	1.209
	Spearthrower	1.512	0.454	0.983	0.718	0.832	0.227	0.529	0.529	0.378
	Bow	0.756	1.436	1.512	1.512	1.663	0.529	0.605	0.454	0.983
Throwing	Spearthrower	1.739	1.436	0.151	0.189	1.058	0.151	0.076	0.302	1.663
	Bow	0.756	1.134	0.529	1.776	1.285	0.227	0.983	0.378	0.227
Spearthrower	Bow	1.285	0.529	0.340	1.512	0.529	0.454	0.983	0.076	1.134

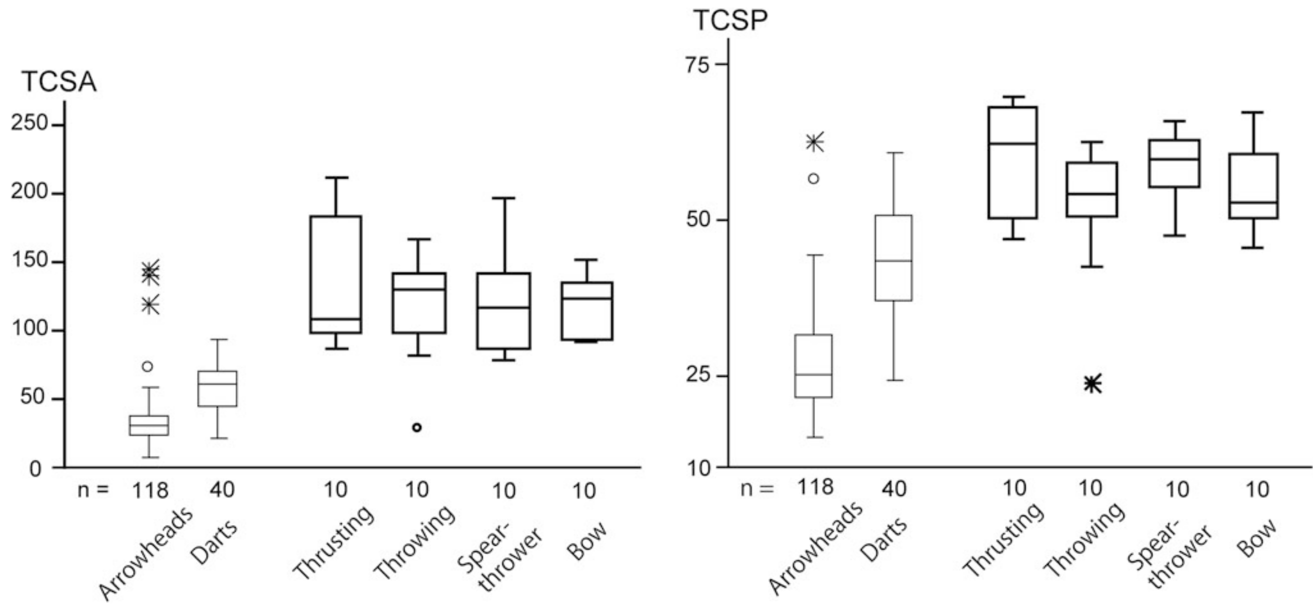

Fig. 3.6 Boxplot of TCSA and TCSP values for the experimental replicas compared with those of the ethnographic arrowheads and dart tips

Table 3.4 Frequency of impact fractures and MLIT. Impact fractures[1] = number of specimens with impact fractures, Impact fractures[2] = total number of the impact fractures, MLIT[1] = number of specimens with MLIT, MLIT[2] = total number of MLIT

	Impact fractures[1]	Impact fractures[2]	MLIT[1]	MLIT[2]
Thrusting	2	2	0	0
Throwing	6	23	4	8
Spearthrower	10	39	7	22
Bow	10	63	9	45

Results

Thrusting

The thrusting experiments produced just two impact fractures and no MLIT (Table 3.4; Fig. 3.7). The impact fractures were too small, making it difficult to distinguish them from micro-flaking formed by trampling or other accidental agencies (Fig. 3.8). Little or no morphological reduction of the specimens occurred due to impact damage. If the same traces are observed on archaeological stone tips, we are unable to determine whether the trapezoids were used as thrusting spear points.

Throwing

Regarding throwing velocity, several distinctive impact fractures were formed (Fig. 3.9). Six out of the 10 specimens included impact fractures and a total of 23 impact fractures were observed (Table 3.4). In addition to the typical DIF, such as flute-like fractures (Fig. 3.10b) and burin-like fractures, evidence of crushing (Odell and Cowan 1986) was frequently found (Fig. 3.10c). The dimension of the impact fractures was larger than that of the thrusting specimens, although half of them were extremely small.

Along with impact fractures, the throwing experiment induced MLIT on four trapezoids (Fig. 3.10a). Although the MLIT on the throwing specimens were generally faint and difficult to recognize, there are specimens bearing MLIT on several parts. Eight MLIT were observed on the throwing spear replicas.

Spearthrowers

The frequency of impact fractures in the spearthrower experiment was dramatically higher than that in the previous two experiments. All the trapezoids shot at the velocity of a

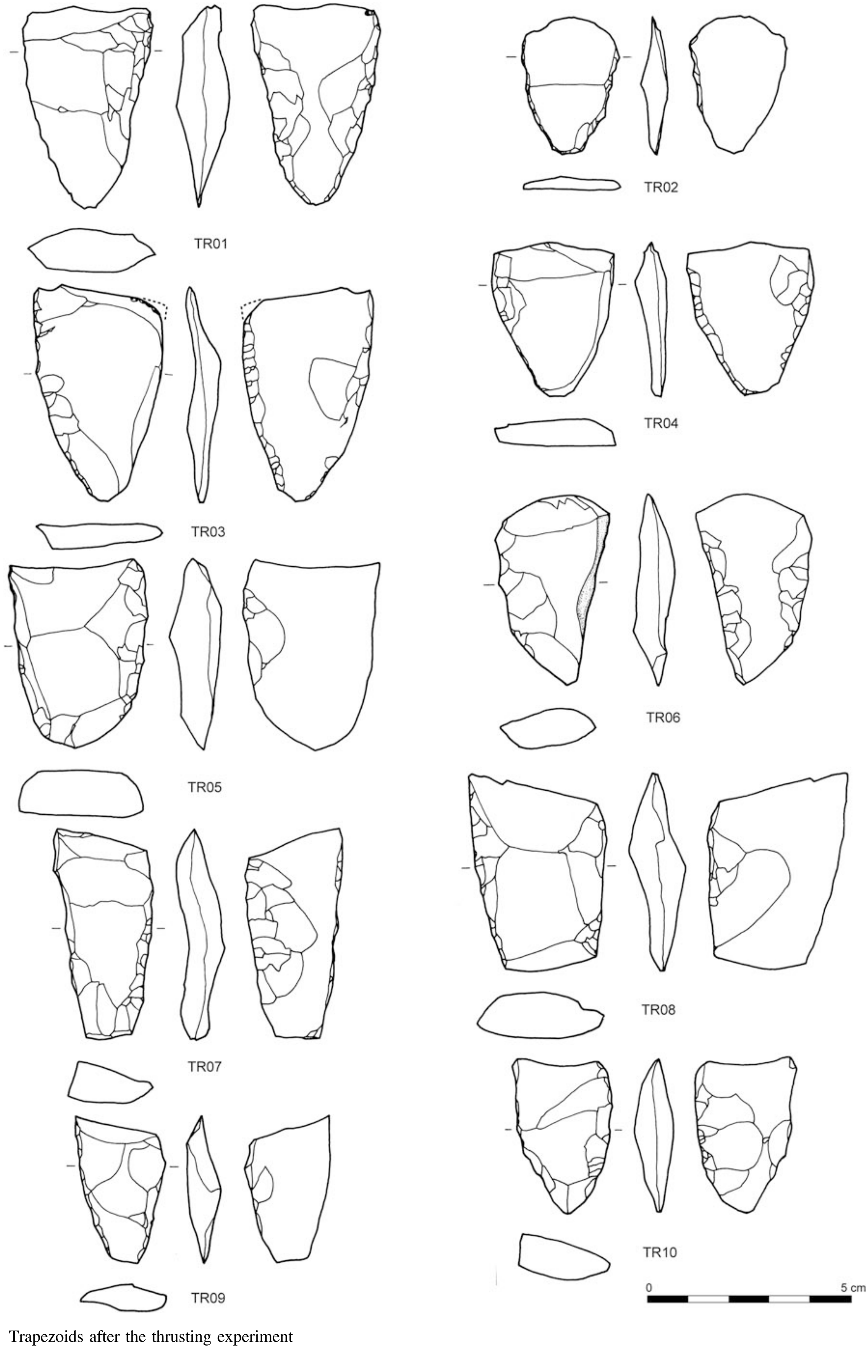

Fig. 3.7 Trapezoids after the thrusting experiment

Fig. 3.8 Specimen with small impact fractures after the thrusting experiment

spearthrower exhibited impact fractures and a total of 39 fractures were observed (Table 3.4; Fig. 3.11). The dimensions of the flute- and burin-like fractures were larger than those of the throwing specimens, and most of them included step or hinge terminations (Fig. 3.12a, b).

The MLIT were formed on seven trapezoids (Fig. 3.12c) and a total of 22 MLIT were observed, more than twice the amount in the throwing experiment. One specimen exhibited a removal on the middle part of the ventral surface, which probably occurred due to hafting (Fig. 3.11: TR26).

Bows

The shooting velocity of bows also generated impact fractures on all the specimens (Table 3.4; Fig. 3.13). There was almost twice the number of impact fractures than that for the spearthrowers. Transverse fractures, which break specimens into two or more pieces, occurred due to the bow's high impact energy (Fig. 3.13: TR35, TR39). Several trapezoids exhibited complex fractures, including transverse, flute-like, burin-like, and spin-off fractures, as well as crushing. Furthermore, most specimens did not maintain their original morphology and broke into several pieces (Fig. 3.14: TR39) with fragments that were too small to be recovered.

MLIT were formed on nine specimens and a total of 45 MLIT were observed (Fig. 3.14a). The numbers of MLIT were larger than that for the spearthrowers. Hafting removals on the ventral surfaces were found on three specimens (Fig. 3.14c), and such removals on the middle surfaces were dissimilar to the hafting traces presented by Rots (2010). This may be a unique hafting scar exclusively formed by a projectile impact.

Discussion

The experiments of thrusting, throwing, spearthrowers, and bows exhibited distinctive results in formation patterns of impact fractures and MLIT. Currently, we discuss the frequency, MLIT, types, and dimension of impact fractures, as well as the volume reduction rate of the specimens to examine whether they provide new indicators for identifying the delivery modes of hunting weaponry.

The ratio of the specimens with impact fractures rose according to the delivery modes, and more impact fractures occurred when the specimens were shot at a higher velocity (Fig. 3.15). In addition, there were positive correlations between impact velocity and the frequencies of the MLIT.

Flute-like fractures and crushing occurred with high frequency in the experiments (Fig. 3.16). The high ratios resulted from the morphological features of trapezoids with vertical edges to the direction of the projectile movement. It is noteworthy that the transverse fractures were formed exclusively when the tips were shot at the velocity of a bow. Trapezoids are generally shorter and thicker than backed points, leaf-shaped points, and microblades, and are thus rarely broken transversely. Consequently, the presence

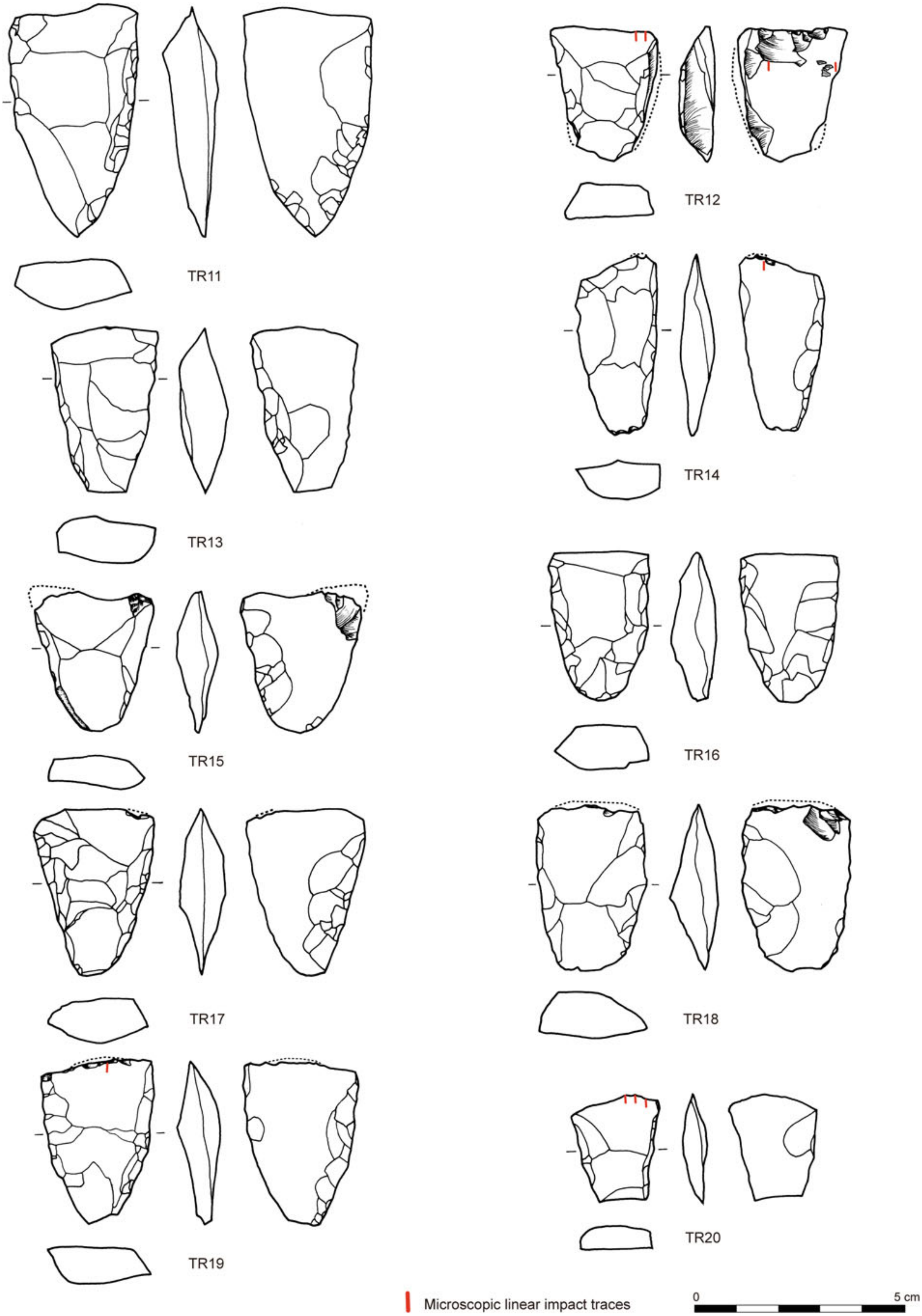

Fig. 3.9 Trapezoids after the projectile throwing velocity experiment

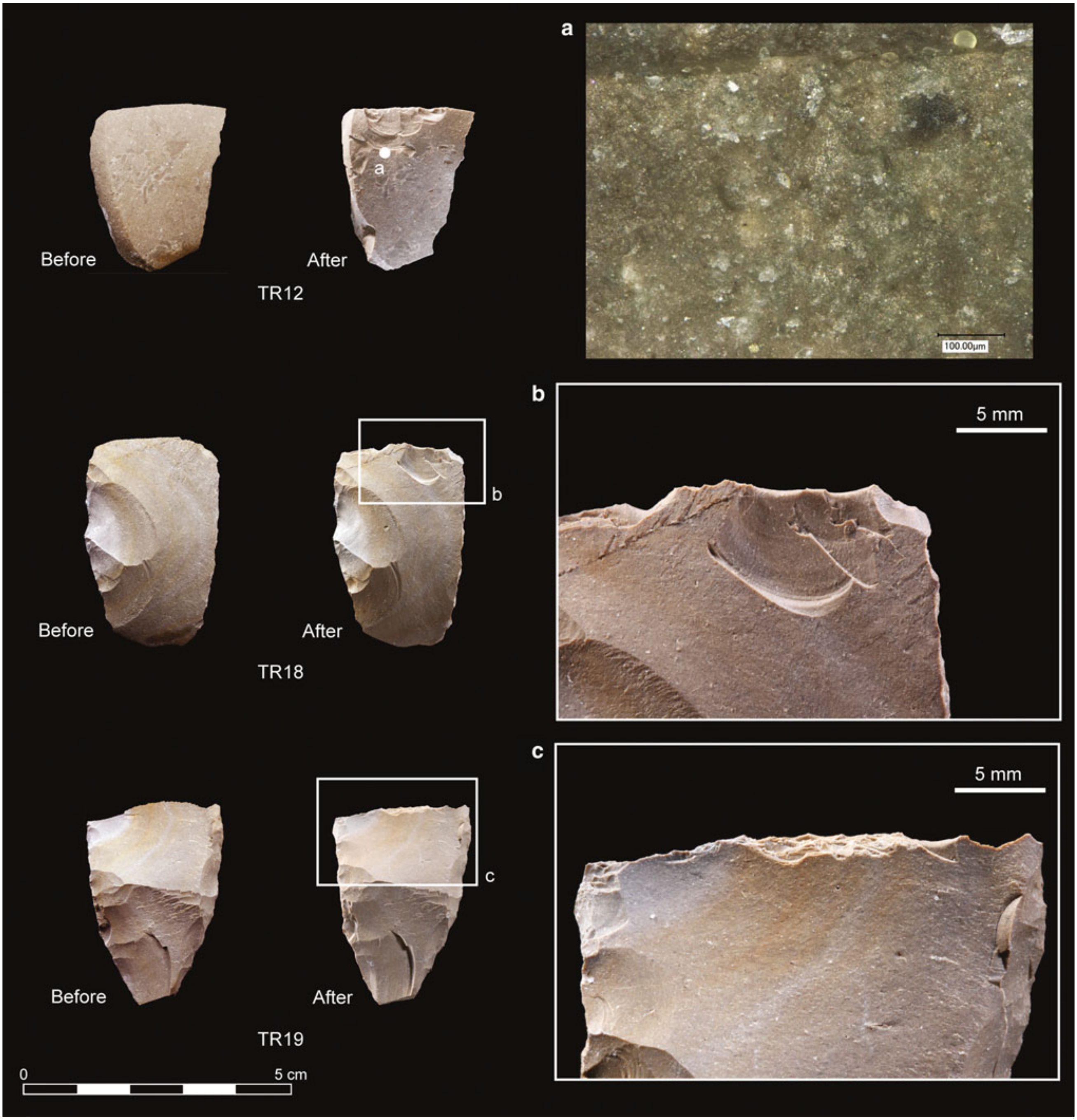

Fig. 3.10 Specimens with impact fractures and MLIT after the throwing velocity projectile experiment: **a** MLIT; **b** flute-like fracture; and **c** crushing

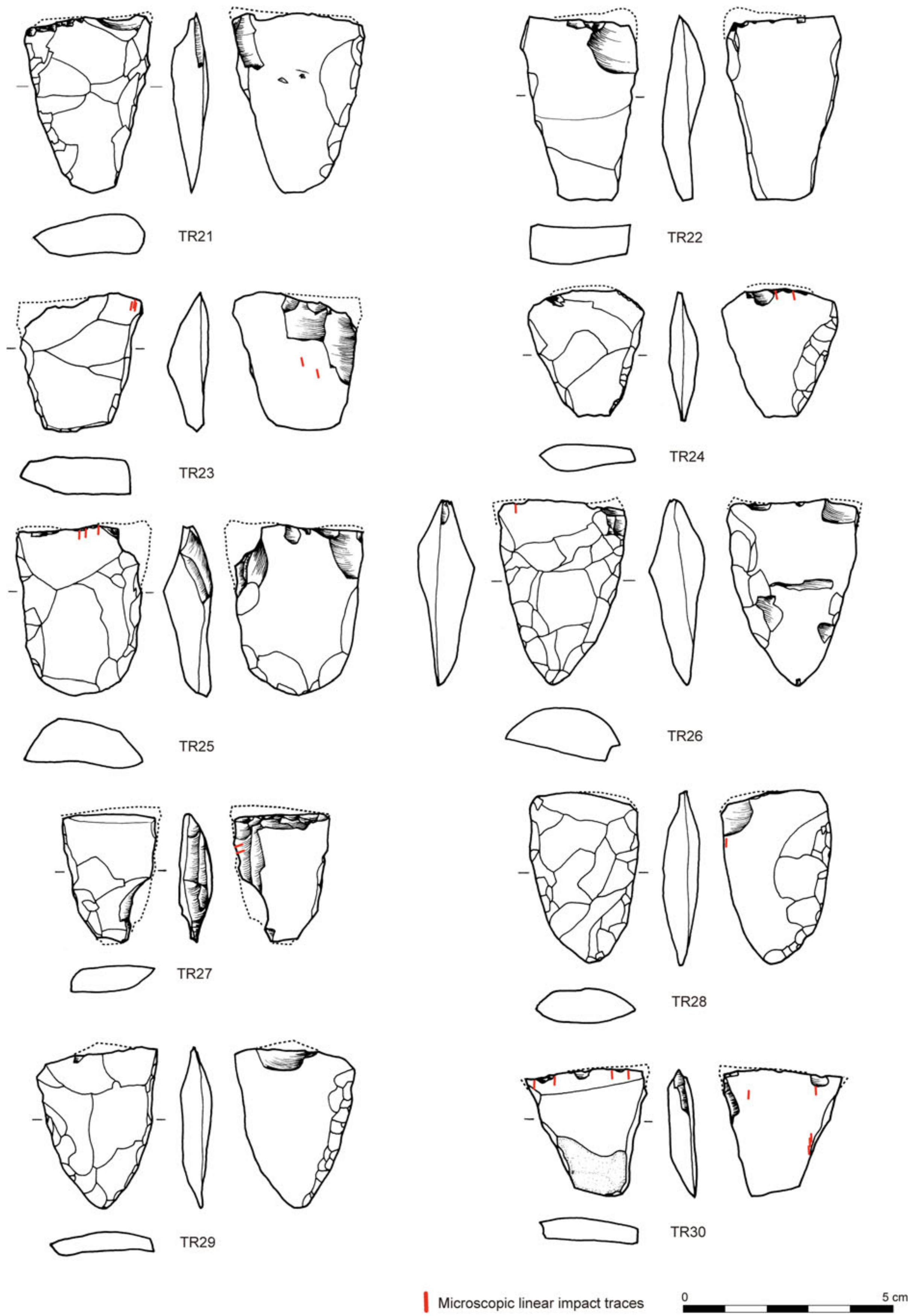

Fig. 3.11 Trapezoids after the spearthrower velocity experiment

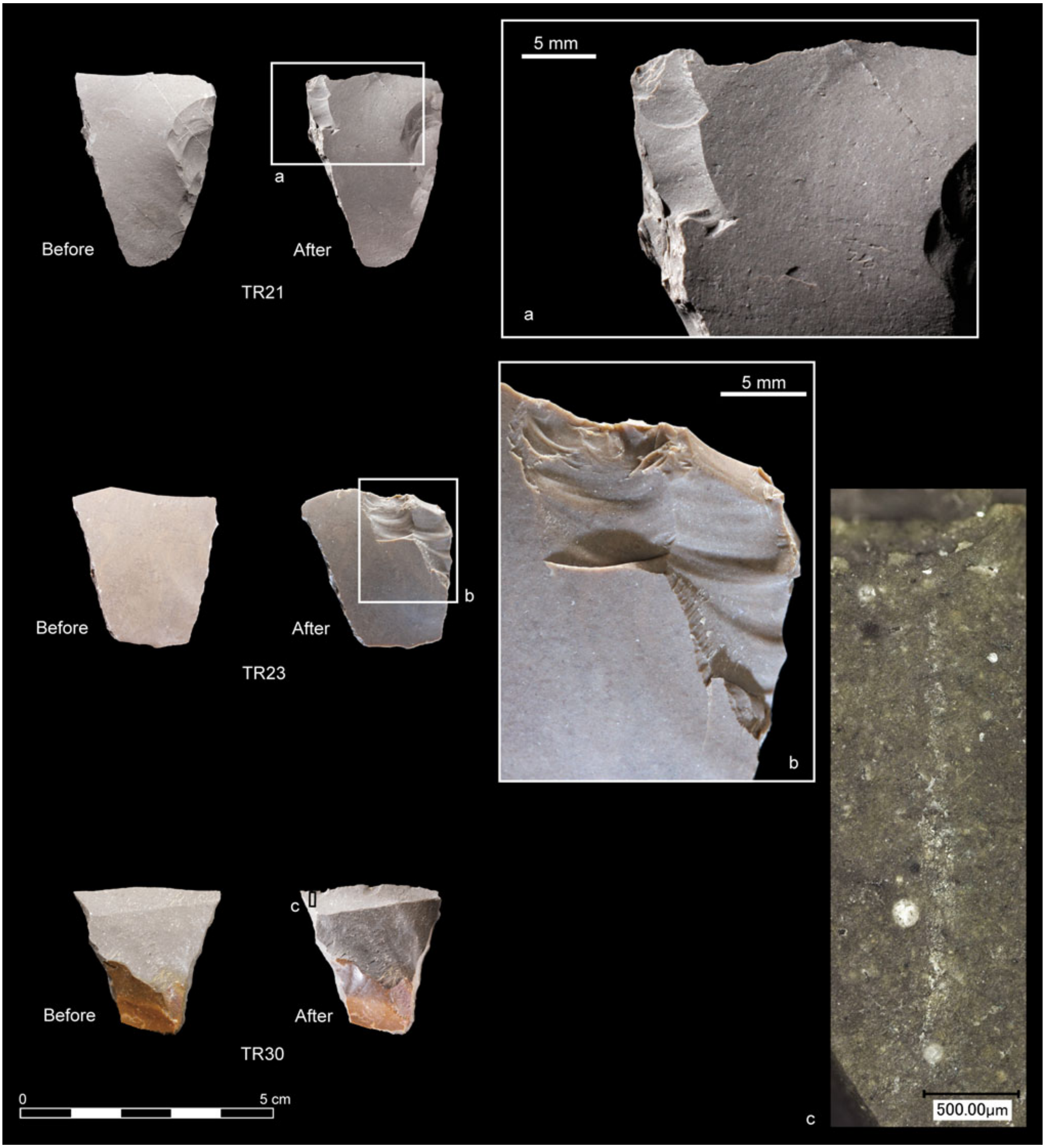

Fig. 3.12 Specimens with impact fractures and MLIT after the spearthrower velocity experiment: **a** burin-like fracture; **b** flute- and burin-like fractures; and **c** MLIT

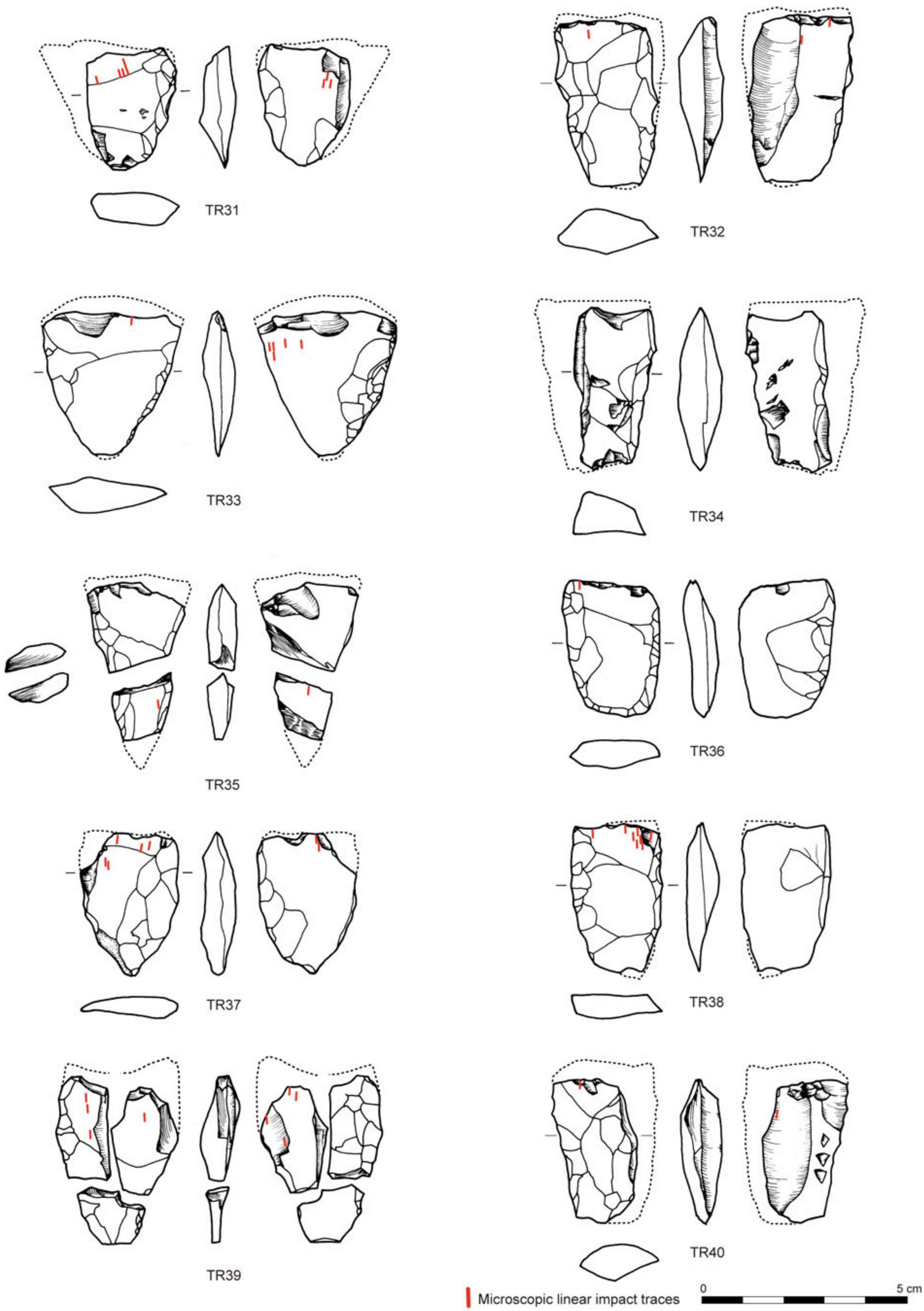

Fig. 3.13 Trapezoids after the bow velocity experiment

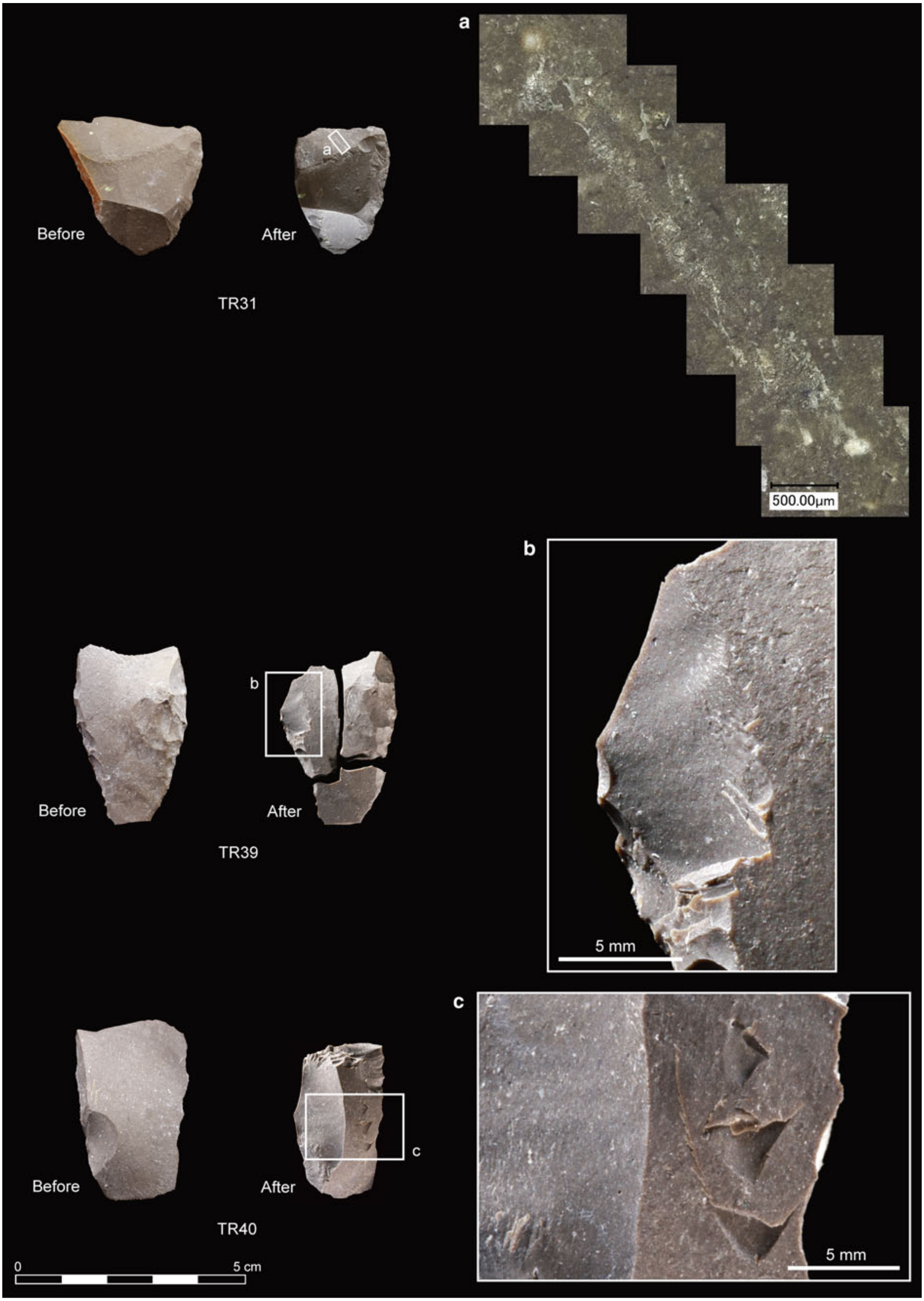

Fig. 3.14 Specimens with impact fractures and MLIT after the bow velocity experiment: **a** MLIT; **b** burin-like fracture; and **c** removals due to hafting

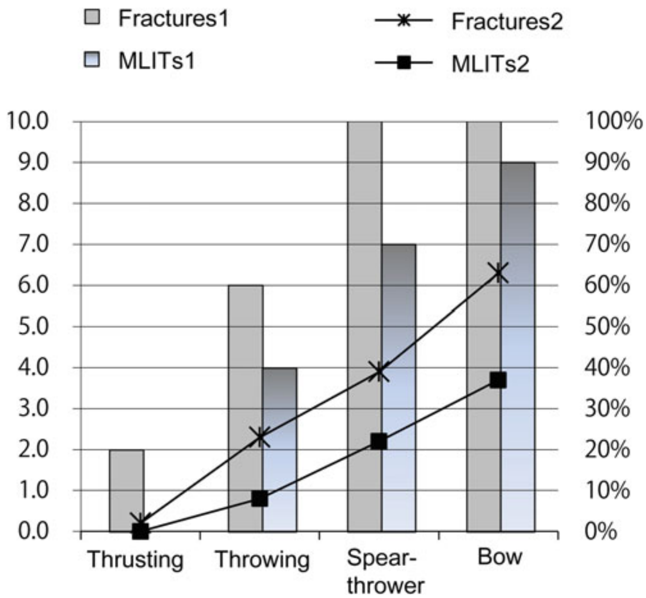

Fig. 3.15 Correlations between the delivery modes and the impact fractures as well as MLIT. Fractures[1] = ratio of the specimens with impact fractures; Fractures[2] = number of impact fractures per specimen; MLIT[1] = ratio of the specimens with MLIT; and MLIT[2] = number of MLIT per specimen

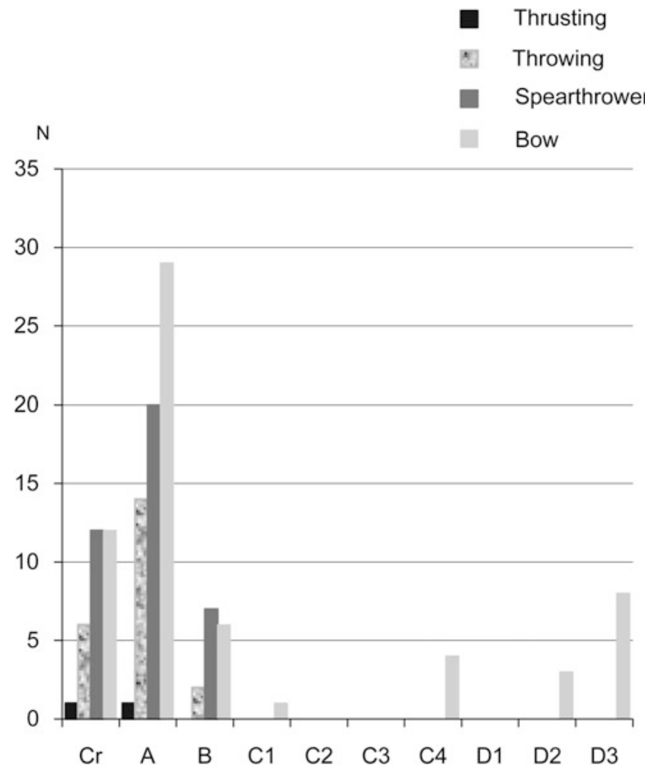

Fig. 3.16 Frequency of the impact fracture types for different delivery modes. Cr: crushing; A: flute-like fracture; B: burin-like fracture; C: transverse fracture; C1: feather termination; C2: hinge termination; C3: step termination; C4: snap termination; D1: bifacial spin-off fractures; D2: spin-off fracture > 6 mm; and D3: spin-off fracture < 6 mm. The fracture types are according to Sano (2009)

of transverse fractures on trapezoids may indicate that the stone tips were fired with high energy by a projectile system.

In addition, there is a correlation between the dimension of impact fractures and the delivery modes (Fig. 3.17; Table 3.5). Thrusting produced impact fractures shorter than 5 mm, while those produced by throwing were no larger than 10 mm, except for one outlier. Conversely, spearthrowers created impact fractures larger than 10 mm, while those created by bows were more than 30 mm, almost as large as the specimens themselves. Therefore, if impact fractures larger than 10 mm were observed, it could be concluded that the stone tips were delivered by either spearthrowers or bows.

Since we confirmed that certain specimens were substantially reduced due to impact damage, the specimen weights were compared before and after the experiments to evaluate the reduction ratio of the pieces (Fig. 3.18). Thrusting created minimal reductions on the specimens. All 10 specimens maintained 100–95% of their original volume. Regarding throwing and spearthrowers, while several trapezoids reduced in volume by over 25%, the majority maintained more than 95% of their original volume. The morphology of tips shot at the velocity of a bow was considerably altered, and two specimens lost over half of their volume, four lost 50–25%, two lost 25–5%, and two lost 5–0%. Accordingly, the high ratio of reduction due to impact damage enabled us to distinguish arrowheads from other hunting weapon tips.

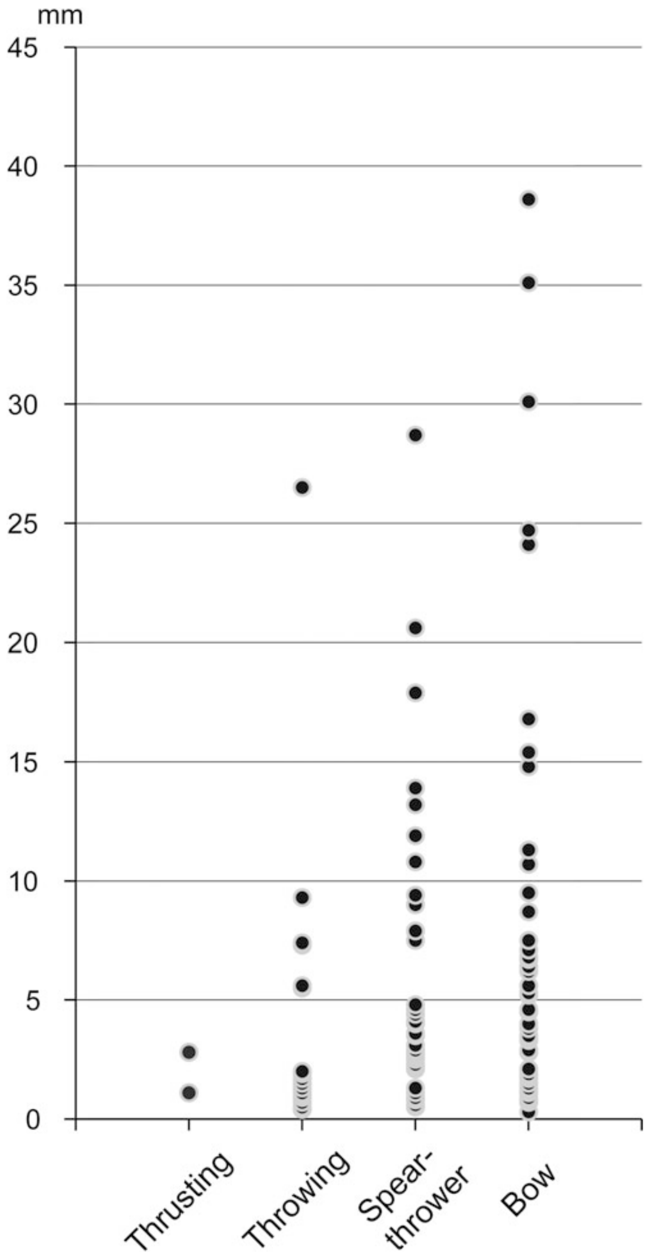

Fig. 3.17 Lengths of the impact fractures for different delivery modes

Table 3.5 Summary of the length (mm) of the impact fractures

	Thrusting	Throwing	Spearthrower	Bow
Number	2	22	39	47
Mean	1.95	3.67	5.74	7.61
Median	1.95	1.5	3.1	4.0
Stdev.	1.20	5.73	6.14	9.08
Min.	1.1	0.4	0.5	0.3
Max.	2.8	26.5	28.7	38.6

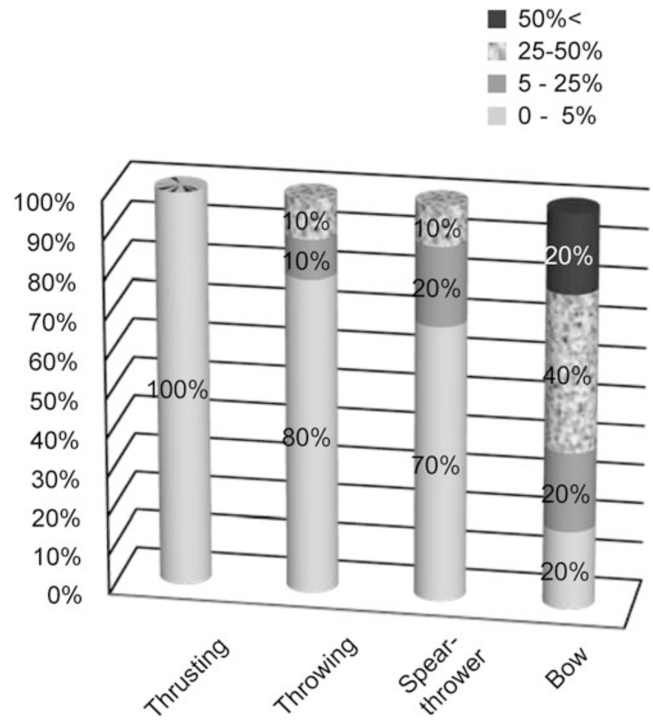

Fig. 3.18 Volume reduction rate of the specimens after the thrusting, throwing, spearthrower, and bow experiments

Conclusions

The results of the aforementioned experiments offered the following conclusions. First, trapezoids rarely experienced transverse fractures owing to their morphological feature, and such fractures occurred only on the bow specimens. Hence, if transverse fractures were observed on trapezoids in archaeological assemblages, we should consider that they may have been shot with bows. In addition, the high reduction ratio of the specimens was an important indicator for the use of bows. It is difficult to accurately estimate the reduction ratio of archaeological tips owing to impact damage. However, if several tips were transversely broken and fragmented, no longer retaining their original morphology, we can assume that these stone tips were used as arrowheads.

Yet, it is worth noting that if the transverse fractures terminated in a snap, they could frequently occur through other agencies such as retouching or trampling (Sano 2009). Therefore, without association with the DIF, including flute-like fractures, burin-like fractures, bifacial spin-offs, and unifacial spin-offs larger than 6 mm (Sano 2009), we cannot conclude that the transverse fractures with snap termination occurred due to hunting. The transverse fractures terminating in a feather, hinge, or step have been recognized as DIF (Fischer et al. 1984; Caspar and De Bie 1996), and they are rarely caused by retouching and trampling (Sano 2009). However, they could accidentally occur from knapping blades (Crabtree 1968; Roche and Tixier 1982; Sano 2009). Therefore, it is necessary to confirm whether the transverse fractures with feather, hinge or step terminations occurred before or after retouching on the lateral sides.

There were significant dimensional differences in impact fractures between delivery modes (see also Clarkson 2016). While thrusting and throwing produced small impact fractures, shooting by spearthrowers and bows frequently yielded impact fractures larger than 10 mm. Thus, impact fractures larger than 10 cm signify that the tips were delivered by spearthrowers or bows.

The frequencies of impact fractures and MLIT were positively correlated with impact velocities. Nevertheless, this cannot be directly used as criteria to evaluate the delivery modes for specific archaeological tips, as we are unaware of the ratio of analyzed archaeological specimens that included stone tips, which were already being utilized as hunting armatures. If the frequencies of impact fractures and MLIT are as low as in the thrusting or throwing experiments, it is difficult to conclude whether this was due to the delivery modes or because most of the analyzed specimens have yet to be used.

If the ratios of the archaeological tips with impact fractures and MLIT without them are similar to those in the throwing experiments, it implies that the use of stone tips comprised primarily of thrusting spears may have been low and that other projectile systems may have existed. The similar ratios of impact fracture occurrences and MLIT to those of the spearthrower experiment suggest that these pieces were shot with either spearthrowers or bows.

The projectile experiments indicated that the formation patterns of the impact fractures and MLIT provide an opportunity to estimate the employed delivery modes. Especially, the presence of the transverse fractures, the dimension of the impact fractures, and the volume reduction ratio are good indicators for distinguishing spearthrower darts and bows and arrows from javelins and thrusting-spears. As this is not the only index for identifying delivery modes, it is important to investigate archaeological specimens by analyzing the frequency, dimension, and types of impact fractures, as well as the volume reduction ratio of the specimens.

However, the results presented in this paper may only be valid for trapezoids (see Iovita et al. 2016 and Clarkson 2016 for comparison), as experiments with backed points showed results different from those for trapezoids (Sano and Oba 2014, 2015). Moreover, the hardness and fragility of raw materials influence fracture formation patterns. In addition, the siliceous shale used in this project is similar to flint, but much harder and less fragile than obsidian. In the future, we will investigate other types of stone tips (such as leaf-shaped points and microblades) to confirm the criteria for identifying the delivery modes within and beyond the variety of tip types. Furthermore, we will examine the influence of different raw materials.

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