Journal of Archaeological Science 38 (2011) 2882–2888

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Assessing the macrofracture method for identifying Stone Age hunting weaponry

Justin Pargeter*

Center for Language and Culture, University of Johannesburg, P.O. Box 524, Johannesburg, South Africa

ARTICLE INFO

Article history:
Received 14 March 2011
Received in revised form
25 April 2011
Accepted 26 April 2011

Keywords:
Hunting
Macrofractures
Experimental archaeology
Trampling

ABSTRACT

Macrofracture analysis is an experimentally derived method used as an initial step in investigating the hunting function of stone artefacts. Diagnostic impact fractures, which can only develop as a result of longitudinal impact, underpin this method. Macrofracture analysis recently gained favour in Middle Stone Age studies, supporting hypotheses for effective hunting during the late Pleistocene in southern Africa. However, the factors affecting diagnostic impact fracture formation and the interpretation of these fracture frequencies are not yet fully understood. This paper outlines a set of experiments designed to test macrofracture formation under human and cattle trampling and knapping conditions. The results show that: (a) macrofractures occur frequently when stone artefacts are trampled by cattle and humans and in knapping debris; (b) diagnostic impact fractures occur on some of the trampled flakes and knapping debris ($\leq$3%), but significantly less often than in previous hunting experiments; (c) when they do occur, they are likely produced by longitudinal forces similar to those experienced during hunting; (d) considering artefact morphology is important during macrofracture analysis; and (e) macrofracture analysis is not a standalone method, but is most useful as part of a multi-analytical approach to functional analysis. These experiments help to establish a significant baseline diagnostic impact fracture frequency for the interpretation of archaeological macrofracture frequencies.

1. Introduction

The cognitive capabilities of prehistoric communities has been assessed using behavioural proxies, such as their reliance on and manufacture of certain hunting weapon types (Shea and Sisk, 2010). Producing mechanically projected weaponry (i.e. bow and arrow), for instance, implies that people are capable of constructing high-tensile strings and sometimes complex adhesives, both of which involve multi-stage planning and assembling processes (Lombard and Phillipson, 2010; Wadley, 2010). These technologies may have assisted in niche broadening among modern humans expanding out of Africa after c. 50 kya, by providing a flexible technology allowing them to focus more intensely on certain foods while broadening their overall dietary base (Sisk and Shea, 2009). Establishing which artefacts were used for hunting, and the types of hunting weapons used are therefore important initial steps towards understanding prehistoric human behaviour and cognition (Rots et al., 2011; Lombard, 2011). At present there are contentious issues around when and where different hunting weapon types appear in the archaeological record (Villa and Soriano, 2010; Hutchings, 2011). This is partly because the organic components of hunting weapons rarely survive over extended periods of time. Archaeologists, therefore, rely mostly on contextual evidence, such as macrofracture patterns to interpret prehistoric hunting technologies (Dockall, 1997; Lombard and Phillipson, 2010).

1.1. Background to the macrofracture method

A macrofracture can be defined as a fracture that is visible with the naked eye or with a hand lens. Diagnostic impact fractures (DIF's) are macrofractures that have been shown through experiments to be associated with stone artefacts used as weapon tips. The assumption is that these fractures are caused by longitudinal impact during use (e.g. hunting), and that variations of this use will leave different breakage patterns on the tools (Dockall, 1997). Macrofracture analysis employs the types, frequencies and patterns of fractures, especially DIF's, on stone tools to detect whether a tool was used for hunting (Fischer et al., 1984; Lombard, 2005; Lombard and Pargeter, 2008).

There are four main DIF breakage types: step terminating bending fractures; spin-off fractures $>$ 6 mm; bifacial spin-off fractures and impact burinations (for more detail on the various fracture types see Fischer et al., 1984 and Lombard, 2005). The interpretive fracture framework provided by studies in the

* 25 Loder St, Rye, New York 10580, USA. Tel.: +1 9142550980.
E-mail address: Justin.pargeter@gmail.com.

0305-4403/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jas.2011.04.018

mechanical sciences and brittle solids research provide a means of distinguishing these key fracture types from those created in other ways (Cotterell and Kamminga, 1979, 1987; Dockall, 1997). Step terminating fractures and spin-off fractures have been referred to as the primary DIF types to identify the potential use of stone-tipped weaponry (Lombard, 2005; Lombard and Pargeter, 2008; Villa et al., 2009). Snap, feather and hinge terminating fractures and tip crushing are recorded during macrofracture analyses to describe the complete range of damage seen on a tool. Such damage can result from a variety of other activities (such as trampling and knapping) and should not be used alone as potential indicators of projectile impact (Villa et al., 2009: 855).

1.2. Diagnostic impact fracture frequencies

Diagnostic impact fractures occur in a variety of combinations, positions and frequencies that are potentially influenced by the material the weapon strikes, the speeds at which the weapon is projected, the various angles of impact and the rock types involved (Odell, 1981; Bergman and Newcomer, 1983). Identifying predictable statistical patterns in DIF formation has therefore proven to be quite difficult (cf. Lombard and Pargeter, 2008). Villa et al. (2009) state that higher DIF frequencies ($\geq$40%) can be expected from kill sites as opposed to residential sites as higher numbers of broken tools associated with hunting activities should be found at such sites. Beyond these observations it is not possible, at present, to interpret what actual DIF frequencies from individual archaeological sites mean in relation to one another.

1.3. Limitations of the macrofracture method

Current macrofracture experiments are contributing to our database of hunting-related fracture types and have begun to show which variables are important for the formation of macrofractures and which are not (Yaroshevich et al., 2010). At present the formation of macrofractures is suggested to be independent of rock type, artefact shape and size (Lombard et al., 2004). However, these suggestions have not been assessed in further experiments and so the effects of these variables on the frequency and size of macrofractures is not known. As a result, we cannot be certain that all macrofractures were formed in a particular way.

These factors are compounded by inter-analyst variability in recording macro-traces on tools as well as process of equifinality that act to mimic hunting-related macro-traces (cf. Schoville and Brown, 2010). These obstacles stem from the fact that archaeologists analyse stone artefacts that have likely undergone a series of alterations since they were manufactured e.g. through trampling, sediment compaction, human handling etc. Many of these alterations are not linked to the original function/s of the artefacts and could possibly have resulted in the formation of macro-traces. A key means to address these concerns is through controlled experiments which identify the traces left on artefacts as a result of specific situations (Keeley, 1980). Being able to link statistical macro-wear patterns observed during experiments to patterns observed on archaeological specimens is a critical part of this process. Understanding the threshold of statistically significant DIF frequencies, derived from experimental studies of post-depositional processes, has also become a necessary step in bridging the gap between observed experimental and expected archaeological fracture frequencies.

2. The experiments

Previous human and animal trampling studies and experiments have focused on the role of trampling in: artefact displacement (Villa and Courtin, 1983; Gifford-Gonzalez et al., 1985; Nielsen, 1991; Eren et al., 2010), lithic modification (McBrearty et al., 1998; Lopinot and Ray, 2007), bone modification (Dominguez-Rodrigo et al., 2009; Gaudzinski-Windheuser et al., 2010) and its effects on soils and vegetation (Liddle, 1975; Weaver and Dale, 1978). Some of these studies have shown that human trampling can obliterate previous use-wear on artefacts (Shea and Klenck, 1993), produce pseudo tools and use-wear (Bordes, 1961; Shea and Klenck, 1993; McBrearty et al., 1998) and can also produce random scar patterns (Tringham et al., 1974; Keeley, 1980). Human and animal trampling has been shown to mimic 'cut marks' on bone (Fiorillo, 1984; Behrensmeyer et al., 1986; Haynes, 1986; Olsen and Shipman, 1988) and to create pseudo bone tools (Brain, 1967; Myers et al., 1980). All of these studies focus on the role of either human or large mammal trampling as taphonomic agents at archaeological and palaeontological sites, but not as agents of macrofracture formation.

The human and cattle trampling experiments conducted in this work move beyond previous trampling studies by:

1. Including cattle as agents of fracture formation on stone artefacts;
2. Comparing the macrofracture results from trampling by cattle and humans;
3. Investigating the formation of a very specific set of fractures, DIF's, under both human and cattle trampling conditions;
4. Testing the formation of macrofractures on locally available rock types (dolerite, milky quartz and quartzite) relevant to the southern African archaeological record.

The experiments in this paper were designed to assess whether macrofractures, specifically DIF's, would form on unretouched stone flakes made from dolerite, milky quartz and quartzite (a) when they are trampled by cattle or humans or (b) during hard hammer direct percussion knapping.

The aims of these experiments were:

1. To determine whether macrofractures, DIF's in particular, occur on unretouched stone flakes when trampled by humans or cattle;
2. To assess the formation of DIF formation on hard hammer direct percussion knapping debris;
3. To observe whether these fractures occur on parts of flakes that analysts would associate with hunting activities, such as tips.

Fig. 1. Trampling area in front of cattle kraal entrance.

Fig. 2. Cattle (left) and human (right) trampling in front of cattle kraal.

The initial question addressed in these experiments was whether tools would be subject to different forces during trampling and knapping than during hunting, and whether the flakes would, therefore, not accumulate DIF's. If DIF's occurred during these experiments, then could this be the result of the same longitudinal forces being produced during trampling as are experienced during the impact forces of hunting (see Shea and Klenck, 1993: 176)? These aims and questions were evaluated in two sets of trampling experiments consisting of one cattle and one human trampling per set. The knapping debris, from manufacturing the experimental flakes, was also examined for macrofractures.

2.1. Experimental materials

The unretouched flakes used in the first human and cattle trampling experiments were manufactured from milky quartz and dolerite sourced from the southern region of Malawi. The knapping technique employed was direct hard hammer percussion with a dolerite cobble. Quartzite was sourced fairly late into the experiments, from the Karonga district in northern Malawi, and was therefore used only for the last cattle trampling experiment as well as the knapping debris analyses. These rock types were chosen for experimentation as they were used by some prehistoric stone tool makers in southern Africa (Wadley, 1986; Orton, 2004; Delagnes et al., 2006; Wadley and Jacobs, 2006; Henshilwood, 2008; Wadley and Mohapi, 2008) and only one previous experiment (Lombard et al., 2004) has dealt with macrofracture formation on local southern African rock types.

The trampling experiments were conducted outside a cattle kraal in southern Malawi (see Fig. 1). This kraal has an entrance that is approximately 1.3 m wide and acted to control the movement of cattle into the kraal. The area selected for the trampling experiments was located just before this entrance. The dominant substrate here is a sandy clay soil with some larger rock and sand inclusions. The same area and substrate were used in both the cattle and human trampling experiments as previous tests have shown soil type to be a variable in trampling experiments (see Villa and Courtin, 1983; Gifford-Gonzalez et al., 1985; McBrearty et al., 1998). A rectangular area measuring 3 $\times$ 2 m was demarcated outside a cattle kraal for the trampling experiments. This was a large enough area to allow for the distribution of the 100 stone flakes (150 for the second cattle trampling experiment, which included 50 quartzite flakes). In this area, a pit was excavated to a depth of 12 cm for the cattle trampling experiments. The last 2 cm were covered with soil to prevent the bottom most flakes from sitting on a harder substratum, which could cause them to break more easily (cf. Gifford-Gonzalez et al., 1985; Nielsen, 1991; McBrearty et al., 1998). Half of each raw material sample, 25 pieces, was placed at a depth of 10 cm, and the other half just below the surface, to assess whether the formation of macrofractures was affected by the depth at which they were placed during cattle trampling. The cattle trampled this area for 15 min twice a day for 27 days, whilst the two human trampling experiments were conducted for 30 min each (see Fig. 2).

2.2. Trampling agents

A herd of 40 cattle were used in the two cattle trampling experiments. Domesticated cattle in Africa are large enough to be comparable to ungulates living during the Pleistocene and Holocene in Africa, such as zebra (*Equus burchelli*) and wildebeest (*Connochaetes taurinus*). The herd used in these experiments also included smaller, younger individuals ($n = 10$) that are comparable in size to smaller bovids such as impala (*Aepyceros melampus*) known to have been important prey items during the Middle and Later Stone Ages in Africa (Turner, 1986; Plug and Engela, 1992;

Table 1
Detailed macrofracture results from the trampling and knapping assemblages. (CT: cattle trampling; HT: human trampling. D: dolerite; Mq: milky quartz; Qtz: quartzite; BF: bifacial; UF: unifacial. Note that one tool may have more than one fracture on it).

	CT1		CT2			HT1		HT2		KNAP D		
	D	Mq	Qtz	D	Mq	D	Mq	D	Mq	D	Mq	Qtz
Number of pieces	50	50	50	50	50	50	50	50	50	122	122	83
Step terminating	2	0	0	0	0	0	0	0	2	1	1	0
BF spin-off	0	0	0	0	0	0	0	0	0	0	0	0
UF spin-off <6 mm	0	0	0	0	0	0	0	0	0	0	0	0
UF spin-off >6 mm	0	0	0	0	0	0	0	0	0	1	0	0
Impact burination	0	1	2	0	1	0	0	0	1	1	1	1
Hinge/feather term.	1	1	15	1	1	3	1	5	4	10	11	9
Notch	7	12	2	2	2	5	1	2	2	0	0	0
Snap	22	23	26	9	25	28	28	20	36	23	32	29
% of Tools with DIF's	4	2	2	0	2	0	0	0	6	2.5	1.6	1.2

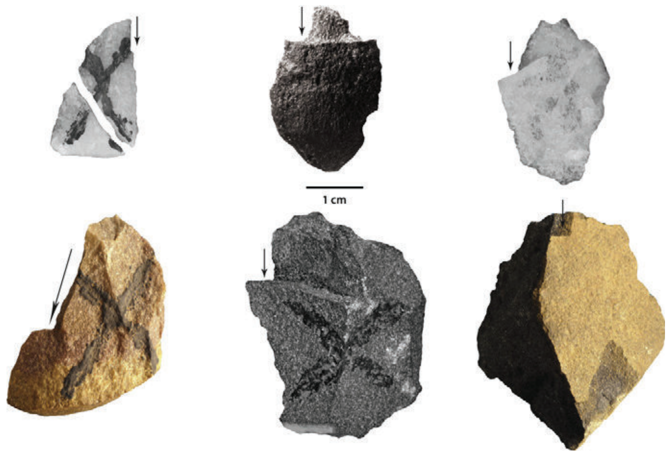

Fig. 3. A selection of DIF's from the trampling and knapping experiments. 1. Impact burination on a cattle trampled milky quartz flake; 2. Step termination on a dolerite knapping debris; 3. Step terminating fracture on a human trampled milky quartz flake; 4. Impact burination on a cattle trampled quartzite flake; 5. Step termination and hoof scuff marks on a cattle trampled dolerite flake; 6. UF spin-off fracture >6 mm on a dolerite knapping debris.

Clark and Plug, 2008). The effects of these cattle on the stone artefacts are analogous to a herd of wild bovids trampling a lithic assemblage in an open-air environment.

The human trampling experiments were conducted with six individuals of varying weight, height and sex, wearing only socks, for a period of 1 h per experiment. This experiment was comparable in length to previous human trampling experiments (Tringham et al., 1974; Gifford-Gonzalez et al., 1985; McBrearty et al., 1998). Whilst the number of participants in this experiment was lower than the 30 people in an average old world forager group (cf. Marlowe, 2005) it was similar to Dobe dry season camp sizes in the Kalahari Desert, which can be as low as five or six individuals (Yellen and Harpending, 1972). The movement of the human tramplers was confined in order to simulate the movement of a group of people within a rock shelter or other restrained area with beacons inside the 3 × 2 m trampling area.

3. Results

Step terminating fractures and impact burinations were the most common DIF types found in all of the experiments (see Table 1 and Fig. 3). No bifacial spin-off fractures were noted on the trampling and knapping flakes. These fractures therefore appear to be the most reliable of DIF types. A single unifacial spin-off fracture >6 mm was noted amongst the knapping debris (see Fig. 3). The milky quartz flakes in the second human trampling experiment had the highest DIF frequency (6%), while the dolerite flakes from the first cattle trampling experiment had the second highest DIF frequency (4%). The highest DIF frequencies in the knapping debris were recorded on the dolerite pieces (2.5%). Except for the first cattle trampling experiment, the dolerite flakes appear to have fractured less often than the milky quartz or quartzite flakes.

The greatest distinction in DIF frequencies between the three experiments in this study (human trampling, cattle trampling and knapping) was between the trampling and knapping experiments. The trampling experiments generally produced a higher number of DIF's compared with the knapping experiments (see Table 1). Differences between human and cattle trampling were slight although the cattle trampling experiments did produce marginally higher DIF frequencies. Snap and hinge/feather fractures were the most frequent non-diagnostic macrofractures in all the experiments, while smooth semi-circular notches occurred occasionally on some of the trampled flakes and knapping debris.

4. Discussion

4.1. Assessing the macrofracture method

The primary aim of this work was to assess the macrofracture method for detecting ancient hunting weaponry. This was done partly by comparing the trampling and knapping experimental results presented in this study to previous hunting macrofracture experiments using a two-tailed Fisher's exact test (see Table 2). The DIF frequencies from two previous hunting experiments (Lombard et al., 2004; Pargeter, 2007; Lombard and Pargeter, 2008) were combined and compared to the DIF frequencies from the trampling and knapping experiments in this study. These hunting experiments were selected as they used the same macrofracture methodology, and because detailed information per tool is available. Therefore, these results were directly comparable. In addition the Fischer et al. (1984) experiments were compared to the experimental samples from this study using only DIF means because their original tool data is not available.

The results of the exact test were show that trampling and knapping produce DIF frequencies significantly different from previous hunting experiments ($p < 0.0001$) (see Table 2). The trampling and knapping assemblages also appear different to the Fischer et al. (1984) hunting experiments when compared on the level of mean DIF frequencies (see Fig. 4). Similar longitudinal impact forces are probably responsible for the small number of trampling and knapping DIF's as for the hunting DIF's. The high proportion of step terminating fractures and impact burinations suggests that the experimental tools were also subject to frequent bending forces during trampling and knapping.

4.2. Step terminating fractures as a DIF category

The simplest of DIF's are step terminating fractures (Fischer et al., 1984). For this reason, step terminating fractures have been

Table 2
Results of Fisher's exact test on the mean DIF frequencies from previous hunting experiments and the trampled and knapped assemblages in this study (Source: Lombard et al., 2004a; Lombard and Pargeter, 2008. D: dolerite; Mq: milky quartz; Qtz: quartzite; α: alpha level).

	Variable 1	Variable 2	*p*-value (fisher exact)	*p*-value (Monte Carlo)	α value
Test 1	Hunting	Cattle trampling 1	<0.0001	<0.0001	
Test 2	Hunting	Cattle trampling 2	<0.0001	<0.0001	
Test 3	Hunting	Human trampling 1	<0.0001	<0.0001	
Test 4	Hunting	Human trampling 2	<0.0001	<0.0001	0.05
Test 5	Hunting	Knapping D	<0.0001	<0.0001	
Test 6	Hunting	Knapping Mq	<0.0001	<0.0001	
Test 7	Hunting	Knapping Qtz	<0.0001	<0.0001	

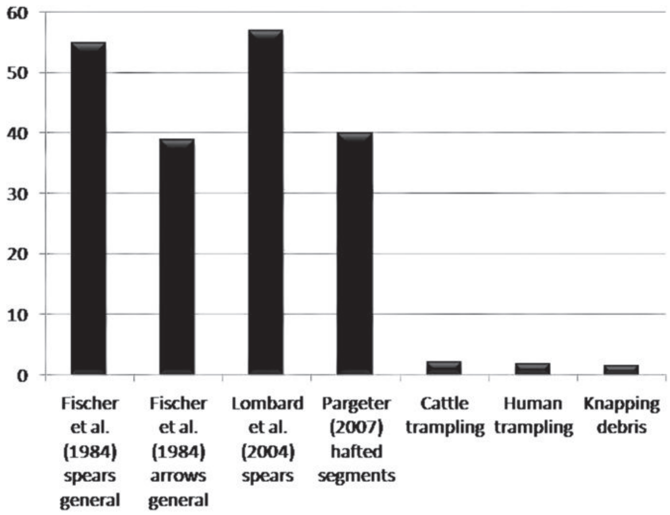

Fig. 4. Comparison of DIF means from three previous hunting experiments and the experimental samples in this study (Source: Fischer et al., 1984; Lombard et al., 2004; Pargeter, 2007; Lombard and Pargeter, 2008).

referred to as one of the primary DIF's to identify the potential use of stone-tipped weaponry (e.g. Lombard, 2005; Lombard and Pargeter, 2008; Villa et al., 2009). Many of the step terminating fractures in this analysis were not found in association with tips and other diagnostic areas of the flakes. However, the six (1.3%) step terminating fractures in direct association with the tips of trampled and knapped pieces suggest that caution be taken when small frequencies of step terminating fractures are recorded on archaeological samples. These fractures should only be considered diagnostic when found on pieces that are morphologically potential hunting weapon components or together with other use-wear traces. Their formation is associated with bending forces that can be produced by a variety of agents amongst which are human feet, cattle hooves and hard hammer percussion.

4.3. Impact burination as a DIF category

Impact burinations originate from longitudinal forces running down the side of a tool to remove a burination spall perpendicular to the axis of the piece (Lombard, 2005). This fracture type was initially not considered diagnostic of projectile use in the experiments by Fischer et al. (1984), but was noted by Barton and Bergman (1982) and Bergman and Newcomer (1983) and was included as a DIF category by Lombard (2005). Since then, burinations have been used to identify the impact function of numerous archaeological stone artefacts. They are a common fracture type on Howieson's Poort (HP) backed artefact assemblages and have been the most frequent DIF type in previous hunting experiments (Lombard and Pargeter, 2008).

Impact burinations were noted on flakes from the knapping debris as well as in the cattle and second human trampling experiments (see Table 1). These fractures can thus also occur when a longitudinal force is applied to the edge of a tool from above, i.e. by the hoof of a cow or a human foot. During the cattle trampling experiments some of the tools were displaced into upright positions (see Fig. 5). These upright flakes are subject to similar forces as a hunting weapon when the hoof of a cow or a human foot stepped downwards onto their edges. This trampling action and direction is similar to the force of a projected weapon impacting an animal. Eight (2.44%) impact burinations were found in association with tips making this the most common DIF type in the experiments. These results suggest that small numbers of burination spalls on archaeological samples should also be viewed with caution in future macrofracture analyses.

4.4. Spin-off fractures as a DIF category

Spin-off fractures are considered to be the most diagnostic of DIF's (Fischer et al., 1984: 23). This observation was confirmed in this set of experiments. Only one spin-off fracture was noted on the trampling and knapping experimental assemblages. This was an unifacial spin-off fracture >6 mm on a snapped medial flake-fragment from the dolerite knapping debris. This one example is not enough to discredit spin-off fractures as a DIF category, but it does suggest that small spin-off fracture frequencies do occur as a result of trampling and knapping.

4.5. Differences between the rock types

Dolerite, a relatively hard and less brittle rock type (between 5 and 6.5 on Moh's scale) (Holmes, 1966; Wadley and Mohapi, 2008) was expected to fracture less frequently than the hard but brittle milky quartz (7 on Moh's scale of hardness) or hard and less brittle quartzite (7 on Moh's scale of hardness) (Howard, 2005). All three rock types in these experiments showed some number of DIF's, with milky quartz fracturing most often. Quartzite fractured slightly less often than dolerite even though quartzite is a more brittle rock type. In general, it appears that the hardness of a rock type is not as important for its rate of fracturing as are the brittleness of its edges.

4.6. Differences between cattle and human trampling

Little distinction was noted in the overall fracture types and frequencies produced by cattle and human trampling. However,

Fig. 5. Upturned flakes (milky quartz) from the first cattle trampling experiment.

cattle trampling did produce slightly more DIF's than human trampling. No DIF's were recorded in the first human trampling experiments, which brings the overall DIF frequency in this experimental group down. The differences between the human and cattle trampling could also be a product of the greater amount of time that the flakes were left in the ground in the cattle trampling experiment. Judging by the similarity of the other fracture categories across the trampling experiments, and my own experimental observations, I suggest that most fracturing takes place within the first few hours of trampling. Afterwards, the tools were generally covered with deposit and were often prevented from further fracturing. The only exceptions to this were the two cattle trampling assemblages, half of which ($n = 50$ for the first experiment and $n = 75$ for the second experiment) were buried at a depth of 10 cm before being trampled. The burial depth did have an effect on the fracture formation process, as almost half the number of macrofractures occurred on flakes at a depth of 10 cm as opposed to those on the surface.

4.7. Differences between trampling and knapping

Macrofractures occurred less frequently from knapping than cattle or human trampling in this study. The knapping DIF's consisted of three impact burinations (0.9%), two step terminating fractures (0.6%) and a single unifacial spin-off fracture >6 mm (0.003%) (see Table 1). A few burination and step fractures were noted in association with platforms as a result of knapping. These were excluded from the analysis as they would be in the macrofracture analysis of an archaeological assemblage (see Lombard, 2005). The knapping debris showed the highest number of DIF's, but the overall sample is also larger ($n = 327$). The likelihood of a DIF forming during knapping, at 1.8% ($n = 6$), is less than during cattle trampling (2.4%; $n = 6$), but greater than during human trampling (1.5%; $n = 3$).

Snap fractures account for 25.7% ($n = 84$) of the debris with fractures. Hinge/feather terminating fractures occurred on 9.2% ($n = 30$) of the debris. No notches were recorded from the knapping debris. In the trampling experiments more of the fragile acute-angled edges were subject to downward forces than during knapping. Trampling notches were often found in association with these acute-angled edges and are therefore not found in the knapping debris.

4.8. Introducing a baseline significant frequency for DIF formation

The DIF's noted on the trampling and knapping experimental assemblages never exceeded 3% of the total number of flakes or debris analysed. The highest DIF frequencies came from cattle trampling (2.4%), followed by knapping (1.8%) and then human trampling (1.5%) (see Fig. 6). These differences are, however, slight and this frequency (≤3%) may be considered a margin of error for macrofracture analyses in the future. This benchmark provides room for researchers to account for the unexpected and unintended post-depositional and manufacturing processes in the past that act to fracture stone artefacts.

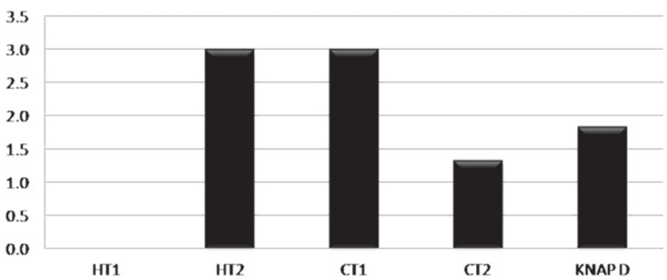

Fig. 6. Overall DIF frequencies from the five experimental assemblages. (HT: human trampling; CT: cattle trampling; Knap D: knapping debris).

5. Conclusions and suggestions for future research

At present, strong interpretive weight rests on the use of the macrofracture method as an initial step in investigating the hunting function of stone artefacts. However, understanding the significance of DIF frequencies has proven to be both a problematic and subjective exercise. This study introduces a means of establishing a baseline significant frequency of DIF's by presenting the maximum DIF percentages resulting from post-depositional and non-hunting processes such as trampling and knapping. The occurrence of step terminating fractures and impact burinations, the most common DIF types produced during the trampling and knapping experiments, indicates that these fracture types need to be used with some caution when they are found in small frequencies (≤3%) in archaeological assemblages. Moreover, the rare occurrence of spin-off fractures >6 mm and absence of bifacial spin-off fractures in these experiments indicates that these are the most reliable of the impact fracture types. Forces acting upon the tools in these experiments were similar to the longitudinal impact forces experienced during hunting, except to a lesser degree. In this case the agent of the impact was not a hunting weapon or animal carcass, but a hoof, foot or hammer stone. These results confirm that the macrofracture method, while a very useful precursory method, cannot be used alone to determine the hunting function of stone artefacts (c.f. Lombard, 2005). The method can only give conclusive results when combined with other strands of archaeological data such as micro-residue and micro-wear analyses, morphometric studies and faunal data for example (Shea et al., 2001; Lombard, 2008; Villa et al., 2009). Lastly, in order for statistical results from experiments such as these to be comparable to archaeological assemblages, there needs to be a persistent emphasis on the probabilistic sampling of archaeological assemblages for macrofracture traces. Otherwise experimental and archaeological analyses are working on two very different levels of sampling and comparison.

The experiments in this project are only an initial step towards creating a firmer understanding of the factors affecting macrofracture formation in post-depositional contexts. Future work should examine macrofracture formation as a result of different post-depositional processes such as dropping tools, rolling rocks over them and trampling by other agents. The statistical threshold (≤3%) of significant DIF formation also needs to be assessed with trampling experiments of different durations to determine whether this variable could affect the frequency of DIF's forming in this way.

Acknowledgements

I wish to thank my supervisors Dr Marlize Lombard, Prof. Christopher Henshilwood and Dr Geeske Langejaans who gave support, advice and input into this project. I would also like to thank my students at the Catholic University of Malawi for participating in the experiments and to Prof. John Shea, colleagues at the University of the Witwatersrand and family for valuable insights on earlier versions of this work. This research was sponsored by the PAST and NRF foundations. I would like to extend my gratitude to the refrees of my paper Prof. John Shea, Dr. Kyle Brown, Dr. Marlize Lombard, Dr. Allah Yaroshivech, Prof. Harold Dibble for their valuable comments.

References

Barton, R.N.E., Bergman, C.A., 1982. Hunters at Hengistbury: some evidence from experimental archaeology. World Archaeology 14, 237–248.

Behrensmeyer, A.K., Gordon, K.D., Yanagi, G.T., 1986. Trampling as a cause of bone surface damage and pseudo-cutmarks. Nature 319, 768–771.

Bergman, C.A., Newcomer, M.H., 1983. Flint arrowhead breakage: examples from Ksar Akil, Lebanon. Journal of Field Archaeology 10, 921–947.

Bordes, F., 1961. Mousterian cultures in France: artifacts from recent excavation dispel some popular misconceptions about Neanderthal man. Science 134, 803.

Brain, C.K., 1967. Bone weathering and the problem of bone pseudo-tools, South Africa. Journal of Science 63, 97–99.

Clark, J., Plug, I., 2008. Animal exploitation strategies during the South African middle Stone Age: Howiesons Poort and post-Howiesons Poort fauna from Sibudu Cave. Journal of Human Evolution 54, 886–898.

Cotterell, B., Kamminga, J., 1979. The mechanics of flaking. In: Hayden, B. (Ed.), Lithic Use-Wear Analysis. Academic Press, New York, pp. 97–112.

Cotterell, B., Kamminga, J., 1987. The formation of flakes. American Antiquity 52, 675–708.

Delagnes, A., Wadley, L., Villa, P., Lombard, M., 2006. Crystal quartz backed tools from the Howiesons Poort at Sibudu Cave. Southern African Humanities 18, 43–56.

Dockall, J.E., 1997. Wear traces and projectile impact: a review of the experimental and archaeological evidence. Journal of Field Archaeology 24, 321–331.

Dominguez-Rodrigo, M., de Juana, S., Galan, A.B., Rodriguez, M., 2009. A new protocol to differentiate trampling marks from butchery cut marks. Journal of Archaeological Science 36, 2643–2654.

Eren, M.I., Durant, A., Neudorf, C., Haslam, M., Shipton, C., Bora, J., Korisettar, R., Petraglia, M., 2010. Experimental examination of animal trampling effects on artifact movement in dry and water saturated substrates: a test case from South India. Journal of Archaeological Science 37, 3010–3021.

Fiorillo, A.R., 1984. An introduction to the identification of trample marks. Current Research in the Pleistocene 1, 47–48.

Fischer, A., Hansen, P.V., Rasmussen, P., 1984. Macro and micro wear traces on lithic projectile points: experimental results and prehistoric examples. Journal of Danish Archaeology 3, 19–46.

Gaudzinski-Windheuser, S., Kindler, L., Rabinovich, R., Goren-Inbar, N., 2010. Testing heterogeneity in faunal assemblages from archaeological sites. Tumbling and trampling experiments at the early-middle Pleistocene site of Gesher Benot Ya'aqov (Israel). Journal of Archaeological Science 37, 3170–3190.

Gifford-Gonzalez, D.P., Damrosch, D.B., Damrosch, D.R., Pryor, J., Thunen, R.L., 1985. The third dimension in site structure: an experiment in trampling and vertical dispersal. American Antiquity 50, 803–818.

Haynes, G., 1986. Spiral fractures and cut mark mimics in noncultural elephant bone assemblages. Current Research in the Pleistocene 3, 45–46.

Henshilwood, C.S., 2008. Holocene Prehistory of the Southern Cape, South Africa. In: BAR International Series 1860. Excavations at Blombos Cave and the Blombosfontein Nature Reserve.

Holmes, A., 1966. Principles of Physical Geology. Thomas Nelson & Sons Ltd, London.

Howard, J.L., 2005. The quartzite problem revisited. The Journal of Geology 113, 707–713.

Hutchings, W.K., 2011. Measuring use-related fracture velocity in lithic armatures to identify spears, javelins, darts, and arrows. Journal of Archaeological Science 38 (7), 1737–1746.

Keeley, L.H., 1980. Experimental Determination of Stone Tool Uses: A Microwear Analysis. University of Chicago Press, Chicago.

Liddle, M.J., 1975. A selective review of the ecological effects of human trampling on natural ecosystems. Biological Conservation 7, 17–36.

Lombard, M., 2005. A method for identifying Stone Age hunting tools. The South African Archaeological Bulletin 60, 115–120.

Lombard, M., 2008. From testing times to high resolution: the late Pleistocene middle Stone Age of South Africa and beyond. South African Archaeological Bulletin Goodwin Series 10, 180–188.

Lombard, M., 2011. Quartz-tipped arrows older than 60 ka: further use-trace evidence from Sibudu, KwaZulu-Natal, South Africa. Journal of Archaeological Science 38 (8), 1918–1930.

Lombard, M., Parsons, I., van der Ryst, M.M., 2004. Middle Stone Age lithic point experimentation for macro-fracture and residue analyses: the process and preliminary results with reference to Sibudu Cave points. South African Journal of Science 100, 159–166.

Lombard, M., Pargeter, J., 2008. Hunting with Howiesons Poort segments: pilot experimental study and the functional interpretation of archaeological tools. Journal of Archaeological Science 35, 2523–2531.

Lombard, M., Phillipson, L., 2010. Indications of bow and stone-tipped arrow use 64 000 years ago in KwaZulu-Natal, South Africa. Antiquity 84, 1–14.

Lopinot, N.H., Ray, J.H., 2007. Trampling experiments in the search for the earliest Americans. American Antiquity 72, 771–782.

Marlowe, F.W., 2005. Hunter-gatherers and human evolution. Evolutionary Anthropology 14, 54–67.

McBrearty, S., Bishop, L., Plummer, T., Dewar, R., Conard, N., 1998. Tools underfoot: human trampling as an agent of lithic artifact edge modification. American Antiquity 63, 108–129.

Myers, T.P., Voorhies, M.R., Corner, R.G., 1980. Spiral fractures and bone pseudotools at paleontological sites. American Antiquity 45, 483–490.

Nielsen, A.E., 1991. Trampling the archaeological record: an experimental study. American Antiquity 56, 483–503.

Odell, G.H., 1981. The morphological express at function junction: searching for meaning in lithic tool types. Journal of Anthropological Research, 319–342.

Olsen, S.L., Shipman, P., 1988. Surface modification on bone: trampling versus butchery. Journal of Archaeological Science 15, 535–553.

Orton, J., 2004. Understanding the role of quartz in the composition of late Pleistocene and Holocene lithic assemblages from the Verlorenvlei Area, Western Cape. Unpublished PhD thesis, Department of Archaeology, University of Cape Town, Cape Town.

Pargeter, J., 2007. Howiesons Poort segments as hunting weapons: experiments with replicated projectiles. South African Archaeological Bulletin 62, 147–153.

Plug, I., Engela, R., 1992. The macrofaunal remains from recent excavations at Rose Cottage Cave, Orange Free State. South African Archaeological Bulletin 47, 16–25.

Rots, V., Van Peer, P., Vermeersch, P.M., 2011. Aspects of tool production, use, and hafting in Palaeolithic assemblages from Northeast Africa. Journal of Human Evolution 60, 637–664.

Schoville, B.J., Brown, K.S., 2010. Comparing lithic assemblage edge damage distributions: examples from the late Pleistocene and preliminary experimental results. Explorations in Anthropology 10, 34–49.

Shea, J.J., Klenck, J.D., 1993. An experimental investigation of the effects of trampling on the results of lithic microwear analysis. Journal of Archaeological Science 20, 175–194.

Shea, J.J., Davis, Z., Brown, K., 2001. Experimental tests of middle Palaeolithic spear points using a calibrated crossbow. Journal of Archaeological Science 28, 807–816.

Sisk, M.L., Shea, J.J., 2009. Experimental use and quantitative performance analysis of triangular flakes (Levallois points) used as arrowheads. Journal of Archaeological Science 36, 2039–2047.

Shea, J.J., Sisk, M.L., 2010. Complex projectile technology and Homo sapiens dispersal into Western Eurasia. Paleoanthropology, 100–122.

Tringham, R., Cooper, G., Odell, G., Voytek, B., Whitman, A., 1974. Experimentation in the formation of edge damage: a new approach to lithic analysis. Journal of Field Archaeology 1, 171–196.

Turner, G., 1986. Faunal remains from Jubilee Shelter, Transvaal. The South African Archaeological Bulletin 41, 63–68.

Villa, P., Courtin, J., 1983. The interpretation of stratified sites: a view from underground. Journal of Archaeological Science 10, 267–281.

Villa, P., Boscato, P., Ranaldo, F., Ronchitelli, A., 2009. Stone tools for the hunt: points with impact scars from a middle Paleolithic site in southern Italy. Journal of Archaeological Science 36, 850–859.

Villa, P., Soriano, S., 2010. Hunting weapons of Neanderthals and early modern humans in South Africa: similarities and differences. Journal of Anthropological Research 66, 5–38.

Wadley, L., 1986. Segments of time: a mid-Holocene Wilton site in the Transvaal. The South African Archaeological Bulletin 41, 54–62.

Wadley, L., 2010. Compound-adhesive manufacture as a behavioral proxy for complex cognition in the middle Stone Age. Current Anthropology 51, 111–119.

Wadley, L., Jacobs, Z., 2006. Sibudu Cave: background to the excavations, stratigraphy and dating. Southern African Humanities 18, 1–26.

Wadley, L., Mohapi, M., 2008. A segment is not a monolith: evidence from the Howiesons Poort of Sibudu, South Africa. Journal of Archaeological Science 35, 2594–2605.

Weaver, T., Dale, D., 1978. Trampling effects of hikers, motorcycles and horses in meadows and forests. Journal of Applied Ecology 15, 451–457.

Yaroshevich, A., Kaufman, D., Nuzhnyy, D., Bar-Yosef, O., Weinstein-Evron, M., 2010. Design and performance of microlith implemented projectiles during the middle and the late epipaleolithic of the levant: experimental and archaeological evidence. Journal of Archaeological Science 37, 368–388.

Yellen, J., Harpending, H., 1972. Hunter-gatherer populations and archaeological inference. World Archaeology 4, 244–253.