

Lithic Production Strategies in the Oldowan Assemblages from Sterkfontein Member 5 and Swartkrans Member 1, Gauteng Province, South Africa

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Abstract

Sterkfontein Member 5 East (Oldowan Infill) and Swartkrans Member 1 (Lower Bank) represent the largest concentrations of Oldowan artefacts in southern Africa, and yet they vary significantly in terms of raw material use and typological frequencies. While previous research has described these differences in detail, questions remain as to the cause and implications of this variability. To increase resolution on this matter, this study implements quantitative methods to investigate lithic production strategies at these sites. Results expand upon previous findings concerning differences in raw material use and knapping methods and how these patterns relate to core reduction and flake production. Explanations for these patterns focus on a dichotomy between efficiency and expediency in lithic production, which differ from previous interpretations. As such, variability between these assemblages may relate more to mobility patterns in early hominins within this region and immediate needs for tool use.

Keywords

archaeology – Oldowan – lithic analysis – core reduction – flake production

Résumé

Le Membre 5 Est ("Oldowan Infill") de Sterkfontein et le Membre 1 (« Lower Bank ») de Swartkrans ont livré à eux deux la plus importante collection d'artefacts Oldowayens connue d'Afrique du Sud. Pourtant, les ensembles provenant de ces deux gisements présentent des variations considérables, à la fois typologique et en termes de matières premières lithiques utilisées. Bien que ces différences aient été décrites dans des travaux antérieurs, certaines questions demeurent quant à l'origine de cette variabilité et ses implications. Afin d'améliorer notre compréhension de ces questions, l'étude présentée ici met en œuvre une approche quantitative permettant d'étudier les stratégies de production lithique sur ces deux sites. Nos résultats développent ceux précédemment obtenus sur les différences dans l'utilisation des matières premières lithiques, les méthodes de taille ainsi que le lien entre ces choix, les stratégies de réduction des nucléus et la production d'éclats. Ces modèles de production lithique s'expliquent en grande partie par une dichotomie entre efficacité d'une part et rapidité d'autre part – un point qui diffère des interprétations précédemment proposées. La variabilité entre ces deux ensembles pourrait ainsi être rapportée à des schémas de mobilité des premiers hominins dans cette région et à des besoins d'utilisation d'outils immédiats.

Introduction

Examining Oldowan tool production from raw material collection to artefact discard has provided a unique window into the complexity of early hominin behaviour and cognition (Isaac 1986; Isaac *et al.* 1997; Blumenshine *et al.* 2003, 2008; de la Torre *et al.* 2003; de la Torre 2004; Delagnes & Roche 2005; Stout *et al.* 2005, 2010; Braun *et al.* 2008a, 2008b, 2009a, 2009b; Harmand 2009; Goldman-Neuman & Hovers 2012). This research has identified key methodological concerns for interpreting economic and ecological constraints on tool-making, including raw material selectivity, core reduction intensity and cutting

edge production in flakes (e.g. Blumenschine *et al.* 2003, 2008; Braun & Harris 2003; Delagnes & Roche 2005; Braun *et al.* 2008b, 2008c; Goldman-Neuman & Hovers 2012). While the focal point of this research has provided a wealth of information on East African sites, the South African Oldowan record has yet to benefit from such inquiry. Mapping variability in the Oldowan has become an important concern for understanding early hominin adaptive behaviours (see Hovers & Braun 2009 and references within). However, this research is largely limited to the eastern African Rift Valley sites. Therefore, analyzing lithic production strategies in the South African Oldowan is critical for developing a wider perspective on this matter and provides opportunities for future comparative research.

To investigate lithic production in the South African Oldowan, this study focuses on the two largest assemblages in this region, Sterkfontein Member 5 East (Oldowan Infill) (hereafter STK-M5E) and Swartkrans Member 1 (Lower Bank) (hereafter SWT-M1), both located in the Cradle of Humankind (COH) World Heritage site, Gauteng Province (Fig. 1) (Kuman 2007). Previous work by Kuman and colleagues has documented differences in assemblage formation, raw material use and artefact frequencies between these sites (Kuman 1994a, 1994b, 2003, 2007; Field 1999; Kuman & Clarke 2000; Kuman & Field

2009; Sutton 2012). To further investigate these underlying patterns between the STK-M5 and SWT-M1 assemblages, methods tracing core reduction patterns and cutting edge production in flakes are implemented. While it remains unknown if these sites were contemporaneous, they are technologically similar, i.e. comprised of core and flake components, and proximity to raw material sources is unlikely to have differed dramatically. Therefore, differences in production strategies require investigation. Results presented below suggest that variability in artefact frequencies and metrical attributes relate to differences in core management and reduction strategies.

Background

The Context of the COH Oldowan Assemblages

While a number of sites in the COH preserve Earlier Stone Age artefacts, only two assemblages can be confidently designated as Oldowan, STK-M5E and SWT-M1 (Fig. 2) (Clark 1993; Kuman 1994a, 2007; Sutton 2012). These sites overlap chronologically, STK-M5E has recently been dated to 2.18 – 1.7 Ma using cosmogenics (Granger *et al.* 2015), albeit previous research using ESR generated a much younger date of 1.32 ± 0.08 (Herries & Shaw 2011). SWT-M1 has been dated to 2.31 – 1.64 Ma using U-Pb on bounding

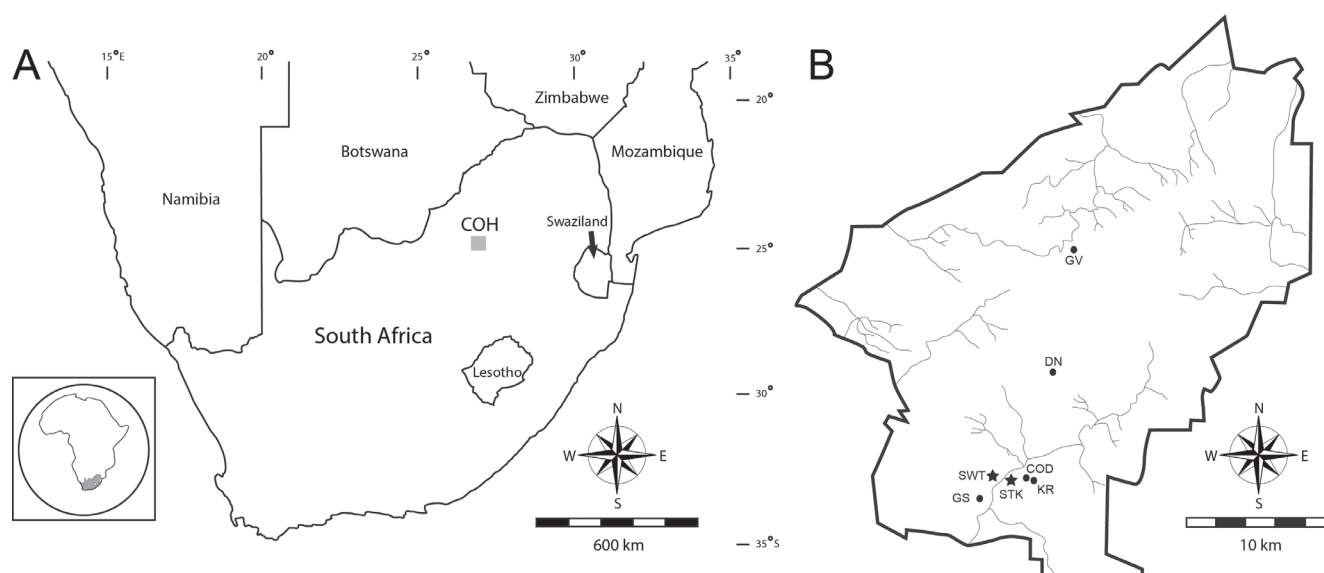


FIGURE 1 A. Map of southern Africa showing the location of the Cradle of Humankind (COH) fossil sites. B. Map of the COH showing the location of Sterkfontein (STK) and Swartkrans (SWT) relative to other Earlier Stone Age localities. (GS = Goldsmiths; COD = Cooper's D; KR = Kromdraai; DN = Drimolen; GV = Gladysvale)

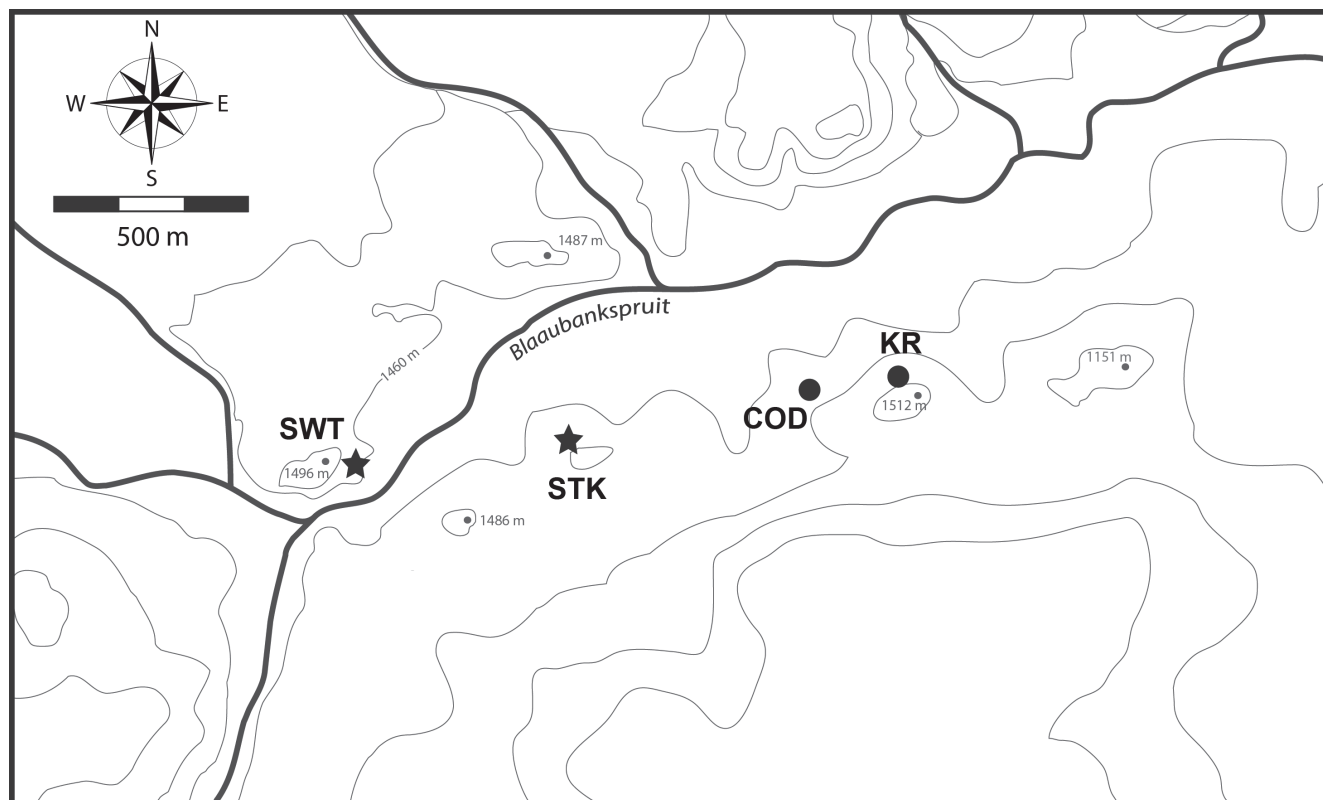


FIGURE 2 Topographic Map of the southwest part of the Sterkfontein Valley showing the location of Sterkfontein (STK) and Swartkrans (SWT) relative to the Blaaubank River.

flowstones for Member 1 deposits, although biostratigraphic data further narrows the age ranges to ~1.9 – 1.8 Ma (Pickering *et al.* 2011). Also new cosmogenic dating have corroborated this range in yielding dates of 2.19 – 1.8 Ma for Member 1 (Gibbon *et al.* 2014). Nonetheless, given the error ranges of dating it is impossible to determine if STK and SWT cave systems were open or frequented by hominins at the same time.

The STK-M₅E and SWT-M₁ assemblages have been described elsewhere in detail (Clark 1993; Field 1999; Kuman 1994a, 1994b, 2007; Kuman & Clarke 2000; Kuman & Field 2009; Sutton 2012). A brief review of the technology and site formation processes is presented to provide context to the challenges of this research. The most significant feature of the COH area is its cave systems that formed through dissolution of the dolomitic limestone host rock (Malmani Subgroup). Cave openings have thus acted as catchment systems for various faunal, hominid and archaeological materials preserved in Plio-Pleistocene infills. From an archaeological perspective, these cave localities have been described as 'keyhole sites' that have captured lithic materials from surface occupations (Kuman & Field 2009). As such, erosional forces driving catchment processes

have affected these assemblages to some degree, although both of the Oldowan collections from Sterkfontein and Swartkrans preserve a range of artefacts including core, flakes and flaking debris.

As such, the assemblages do not represent discreet behavioural events but rather are akin to palimpsests accumulated through infills over hundreds to thousands of years. While attaining behavioural information from these assemblages is challenged by context, the technology and artefact ranges at these sites are firmly representative of the Oldowan Industry. Technological and typological attributes associated with Oldowan assemblages are consistent, marked by core and flake typically produced through hard-hammer and bipolar percussion (Leakey 1971; Plummer 2004). Although behavioural differences cannot be traced to the individual level within these assemblages, they are representative of tool-producing populations that inhabited this region from ~2.2 – 1.7 Ma. Any differences in technological aspects between these assemblages is argued here to reflect the ecological contexts of tool production given the technological consistency (i.e. core and flake production) within the Oldowan industry.

Assemblage Characteristics

The STK-M5E Oldowan Infill has yielded the largest assemblage with 3,500 artefacts and 13 manuports (Kuman & Field 2009). Sixty-five percent of this material is fresh, which attests to knapping activities occurring near cave shaft entrances and its rapid preservation in the Member 5 infill (Kuman 2003). Further, 84.17% of this assemblage is comprised of small flaking debris (<2 cm), likely due to the involvement of slope wash in site formation processes (*ibid.*). Furthermore, the SWT-M1 Lower Bank materials analyzed here is comprised of 277 artefacts and 21 manuports with some differences in the artefact condition and composition (Clark 1993; Field 1999). Previous research has debated the fact that SWT-M1 could be assigned to the Oldowan Industry (Kuman 2007), although new excavations within the Member 1 Lower Bank at Swartkrans has confirmed its Oldowan affiliation (Sutton 2012). In terms of its characteristics, only 37.77% of the assemblage is composed of small flaking debris and over 50% of the artefacts are weathered, suggesting that either this material was exposed on the surface for longer periods or geomorphological differences in slope near the entrance affected catchment during site formation (Field 1999; Kuman 2007).

One of the most significant commonalities of these assemblages is the dominance of quartz as the lithic medium. Both Sterkfontein and Swartkrans cave systems are situated near the Blaaubank River, where quartz clasts are present within its gravel beds, and quartz vein exposures are also found throughout this area (Kuman 1994b). However, quartz is rare in these gravel beds when compared to other rock types such as quartzite and chert (Kuman 1994b; Kuman & Field 2009). Nonetheless, quartz comprises 97.1% of the STK-M5E and 55.79% of the SWT-M1 assemblages suggesting it was purposefully selected, possibly due to its structural properties (Kuman & Field 2009). The trigonal structure of quartz crystals, their massive habit and tendency to split during formation all contribute towards irregular breakage planes that cause a high rate of fragmentation when subject to conchoidal fracture (Deer *et al.* 1992). However, quartz is also a durable material and produces sharp edges in flakes, which may have been a reason for why it was preferred when compared to other toolstone types in the COH Oldowan (Kuman & Field 2009).

In terms of assemblage composition (see Kuman & Field 2009 for definitions), STK-M5E material has a small collection of complete flakes (N= 84) and cores (N= 24). Complete flakes range from 1.9–7.4 cm (mean = 3.5 cm) in length with only 28% bearing cortical surfaces. Interestingly, polyhedral and irregular polyhedral core types comprise 50% of the total core assemblage. The SWT-M1 collections

preserve a smaller number of complete flakes (N= 41) and cores (N= 22) (Field 1999). Complete flakes range from 2.2–9.8 cm (mean = 4.6 cm) in length with 65% bearing cortical surfaces. Polyhedral and casual forms are the dominant core types. While these assemblages bear some similarities in raw material preference and core reduction, significant differences in the intensity of flaking activities have been suggested (Field 1999; Kuman & Field 2009). For instance, Field (1999) argued that the higher number of casual cores and bipolar knapping at Swartkrans represents a more casually-flaked assemblage. By contrast, the dominance of polyhedral cores at Sterkfontein, thought to result from increased exploitation of knappable planes represents a more intensively-flaked assemblage. While these observations offer avenues of investigation, quantitative methods have never been applied to test this hypothesis.

Analyzing these differences might offer insight into the efficiency of lithic production between these assemblages. Parsimony would suggest that production strategies would be similar given that both assemblages are within a 2 km radius of one another, and both draw from similar raw material sources (both within 500 m of the Blaaubank River) (see Fig. 2). However, differences listed above in raw materials frequencies, knapping methods and typological composition suggest a more complex explanation for these assemblage differences. As such, these differences may support heterogeneity in raw material collection patterns and production techniques that requires further explanation.

Materials and Methods

Materials

Analyzing differences in core and flakes from the STK-M5E and SWT-M1 assemblages is complicated by small sample sizes. This in turn affects the robusticity of the statistical analyses of core reduction and flake production presented below. To increase the reliability of statistical comparisons, cores and flakes were bundled into 'quartz' and 'non-quartz' categories. Within the core analysis, core types were grouped according to their exploitation strategies, including unifacial (casual and single-platform), bipolar, bifacial (chopper and discoidal) and multifacial (polyhedral and irregular polyhedral) cores. It should also be noted that new excavations within SWT-M1 have recently yielded more lithic materials (Sutton 2012), although this analysis is restricted to historical collections excavated by C.K. Brain and housed at the Ditsong Museum in Pretoria, South Africa (Clark 1993; Field 1999). Twenty-four cores

from STK-M5E (16 quartz and 8 quartzite) and 22 cores (11 quartz, 7 quartzite, 3 chert and 1 igneous) from SWT-M1 were measured using digital calipers and 3D scanned. Eighty-four complete flakes (57 quartz, 20 quartzite and 7 chert) from STK-M5E and 41 from SWT-M1 (21 quartz, 5 quartzite and 15 chert) were also measured with digital calipers. Table 1 displays core typology and Table 2 displays descriptive statistics (means and standard deviation) for both cores and flakes analyzed in this study.

Methods

Investigating lithic production strategies in Oldowan assemblages has been an important avenue of research concerning the adaptive strategies of early hominins (see Blumenshine *et al.* 2003; Braun *et al.* 2008, 2009). Recently, understanding quantifiable differences in reduction intensity has been highlighted as a source of variation between Oldowan assemblages, which may have a significant influence on artefact morphologies and assemblage composition (Blumenshine *et al.* 2003; Braun *et al.* 2005, 2008b, 2008c; Stout *et al.* 2010). However, allometric effects of initial core size problematize traditional reduction measures in both cores and flakes, such as cortex percentage and scar count rates (Braun *et al.* 2005; Stout *et al.* 2010). With respect for the COH Oldowan material, tracing variability is further compounded by the predominance of quartz, which is notoriously difficult material type to

analyze (Driscoll & Warren 2006). In effort to understand variability in cores between the STK-M5E and SWT-M1 assemblages, a principal component analysis (PCA) was undertaken to trace variation from metric attributes including length, width, thickness, mass (g), scar count and length, cortex percentage. Volume and surface area were generated through 3D scanning using a NextEngine 3D scanner and ScanStudio software. A PCA was chosen to understand the effects of size (represented by PC1) and what other measures might account for the remaining variation (represented by PC2). A correlation matrix was used in this analysis to account for differences in measurement scale between attributes (e.g. scar count vs. maximal length). Furthermore, differences in how core assemblage vary between sites can be graphically displayed through a PCA scatterplot (Fig. 3) and component score regressions (Fig. 4).

Based on the results of the PCA (see below) the Scar Density Index (SDI) was chosen to measure the effects of reduction intensity between the STK-M5E and SWT-M1 core assemblages (Clarkson 2013). Experimental testing of the SDI across raw material types and reduction methods revealed that it predicts mass loss, such that the SDI increases linearly as mass decreases during reduction ($r^2 = 0.718$, $p = <0.0005$) (Clarkson 2013: 4350). SDI values are calculated to compare how the COH Oldowan core assemblages compare in terms of reduction intensity and

TABLE 1 Core typology

Sterkfontein (N= 24)	Quartz	Quartzite	Total	%
Bipolar	3	0	3	13%
Bifacial	1	3	4	17%
Casual	2	0	2	8%
Discoidal	1	0	1	4%
Polyhedral	6	0	6	25%
Irregular Polyhedral	3	3	6	25%
Single Platform	1	1	2	8%
Total	17	7	24	100%

Swartkrans (N= 22)	Quartz	Quartzite	Chert	Igneous	Total	%
Bipolar	2	2	0	0	4	18%
Bifacial	1	1	1	0	3	14%
Casual	2	3	1	0	6	27%
Polyhedral	2	1	0	1	4	18%
Irregular Polyhedral	4	0	1	0	5	23%
Total	11	7	3	1	22	100%

TABLE 2 Core and flake attributes

STK-M5E Cores					STK-M5E Flakes				
Quartz (N= 16)	Length	Width	Thickness	Mass	Quartz (N= 57)	Length	Width	Thickness	Mass
Mean	57.96	48.36	36.61	160.13	Mean	29.78	23.03	9.60	7.09
Standard Deviation	21.26	16.27	12.87	168.10	Standard Deviation	8.78	7.79	3.85	7.62
Non-Quartz (N= 8)					Non-Quartz (N= 27)				
Mean	77.23	63.39	38.20	253.36	Mean	43.72	35.48	11.77	19.31
Standard Deviation	21.00	19.28	13.49	169.56	Standard Deviation	13.30	11.99	5.06	18.76
SWT-M1 Cores					SWT-M1 Flakes				
Quartz (N= 11)	Length	Width	Thickness	Mass	Quartz (N= 21)	Length	Width	Thickness	Mass
Mean	75.33	66.69	49.40	267.62	Mean	3.45	2.86	1.38	34.19
Standard Deviation	11.54	9.86	9.71	163.02	Standard Deviation	1.64	1.46	0.72	35.85
Non-Quartz (N= 11)					Non-Quartz (N= 20)				
Mean	90.83	73.47	52.20	443.15	Mean	6.02	5.11	1.31	38.90
Standard Deviation	26.10	22.08	13.27	275.56	Standard Deviation	2.51	1.85	0.65	19.36

graphically represented through boxplots (Figs 5 & 6). Wilcoxon Rank Sum tests were chosen to test relationships between variables due to the non-normality of data and small sample sizes.

Clarkson (2013) further investigated the effects of core size and shape through calculating surface area to volume^{2/3}, which minimizes scaling effects between these measurements (see Lin *et al.* 2010). He found that increasing SA:V^{2/3} ratio reflects compactness (higher surface area to volume), while lower SA:V^{2/3} ratios reflect sphericity (higher volume to surface area). Regressing the SDI against SA:V^{2/3} also found no significant correlations, which confirms that it tracks material loss during the reduction process irrespective of knapping methods. While the SDI and SA:V^{2/3} are independent variables, Clarkson (2013: 4351) used this relationship to understand how knapping strategies affect reduction trajectories in relation to their shape. This concept is used here to map the relationship between core shape and knapping strategy within the COH Oldowan assemblages (Fig. 7), as well as understand the efficiency of core types in reduction intensity (Fig. 8).

Tracing difference in flake production in terms of cutting edge has also been an important area of research in lithic analysis, typically expressed as a ratio of edge length to mass in grams (EL/M) (Leroi-Gourhan 1964; Braun & Harris 2003; Tactikos 2003; Braun 2005; Lin *et al.* 2013; Dogandžić *et al.* 2015). Tracing cutting edge production has provided insight into how core reduction methods and knapping strategies can maximize flake production in this sense (Diez-Martín *et al.* 2011; Eren *et al.* 2013). To assess this, flake attributes were collected with digital calipers and ImageJ V1.49 software was used to capture flake perimeter and area measurements. However, it was found here that mass does not predict cutting edge production reliably in quartz tools from STK-M5E and SWT-M1. Because of high shatter rates and irregular breakage planes, quartz clasts tend to produce smaller debitage products. As such, low mass values in small flakes inflate the EL/M ratio even though small quartz flakes are more likely to break during use (i.e. provide less utility) when compared to larger-sized flakes. To overcome this issue, the alternative measure of useable cutting edge (UCE)

([Perimeter – Platform Width] / Perimeter) described by Lin *et al.* (2013) is used here, which evaluates the percentage of cutting edge in flakes independent of mass. Another series of boxplot graphs were created to illustrate differences in UCE, as well as perimeter, area and length to investigate the relationship between UCE and overall flake size (see Figs. 11–13). Wilcoxon Rank Sum tests were performed to test for significance in results.

Results

Core Reduction Patterns

The principal component analysis results for core attributes showed that the first two component scores accounted for 84.43% of the total variance within the COH Oldowan core assemblages (see Table 3). PC1 accounts for variation related to size effects, as length, width, thickness, mass, volume and surface area and scar length correlated significantly along the X-axis (Fig. 3). PC2 on the other hand correlated with scar count and cortex percentage. This is interpreted here as variation in core attributes associated with reduction intensity as these measures are directly related to such effects. Interestingly, differences in where these sources of variation between the STK-M5E and SWT-M1 core assemblages are evident in Figure 3. At least some of the variance in the STK-M5E population is explained by reduction effects (PC2), whereas nearly all the variation in SWT-M1 can be explained by size effects (PC1). Thus, SDI (see above) was chosen to further compare reduction effects as scar count loads strongest on PC2, followed by cortex percentage. To verify this, SDI was regressed against both PC1 and PC2 (Fig. 4), which

showed significant correlations. An inverse relationship between SDI and PC1 was found ($r^2 = 0.45$, d.f. = 43, $p = 0.001$), while the opposite trend was found for SDI and PC2 ($r^2 = 0.24$, d.f. = 43, $p = 0.001$). This confirms that notion that decreasing size in cores inversely correlates to increasing SDI, while reduction effects correlate positively with increasing SDI.

Figure 5 demonstrates the relationship between SDI values for cores according to raw material categories in the STK-M5E and SWT-M1 assemblages. This shows that quartz core are more reduced when compared to non-quartz and the STK-M5E assemblage is more reduced when compared to SWT-M1. Wilcoxon Sign Rank tests confirmed this results ($Z = -5.511$, $p < 0.001$). To expand on these findings, core typologies separated by raw materials were also investigated through SDI comparisons. Figure 6 displays SDI mean values peaking in multifacial and bifacial core forms and a Wilcoxon Sign Rank test confirmed significant differences between core types ($Z = -5.522$, $p < 0.001$). This demonstrates that bifacial and multifacial core forms show increased reduction when compared to other core types (e.g. bipolar and unifacial cores). While this is the expected result, it shows the reliability of the SDI to trace reduction within the COH Oldowan core assemblages.

Furthermore, the relationship between core shape and SDI for all COH Oldowan cores was examined to determine the management strategies of particular knapping methods in relation to raw materials (Figs. 7 & 8). Following Clarkson (2013), surface area (SA) and volume ($V^{2/3}$) was compared as a proxy for investigating shape where regression trends towards increasing volume correspond to increasing sphericity and trends towards increasing surface area correspond to increasing flatness (Lin *et al.* 2010; Clarkson 2013). A linear regression showed no correlation between $SA/V^{2/3}$ and SDI values ($F = 0.602$, d.f. = 39, $p = 0.443$), confirming that SDI is not significantly affected by core shape. Figure 7 displays the results of a regression graph comparing core shape (SA to $V^{2/3}$) and Figure 8 compares $SA/V^{2/3}$ to SDI across core types to understand how reduction trajectories relate to knapping strategies within the COH Oldowan core assemblages. Figure 7 shows that most cores show a strong linear relationship between SA and $V^{2/3}$ (i.e. bipolar and multifacial), which relates to increasing sphericity while unifacial and bifacial cores trend slightly towards flatness (proportionally more SA to $V^{2/3}$). Within the $SA/V^{2/3}$ to SDI relationship displayed in Figure 8, all core types show a general trend of increasing SDI relative to their sphericity. Interestingly, unifacial and bipolar cores show that SDI terminates faster when

TABLE 3 Principal component scores for core attributes (first two PC scores displayed)

	PC1	PC2
Length	0.38336	-0.01474
Width	0.37784	0.011562
Thickness	0.35517	0.091305
Mass	0.3818	0.085423
Surface Area	0.39201	0.062998
Volume	0.38211	0.086322
Scar Length	0.26164	-0.02019
Scar Count	0.022176	0.84343
Cortex %	-0.26407	0.5107

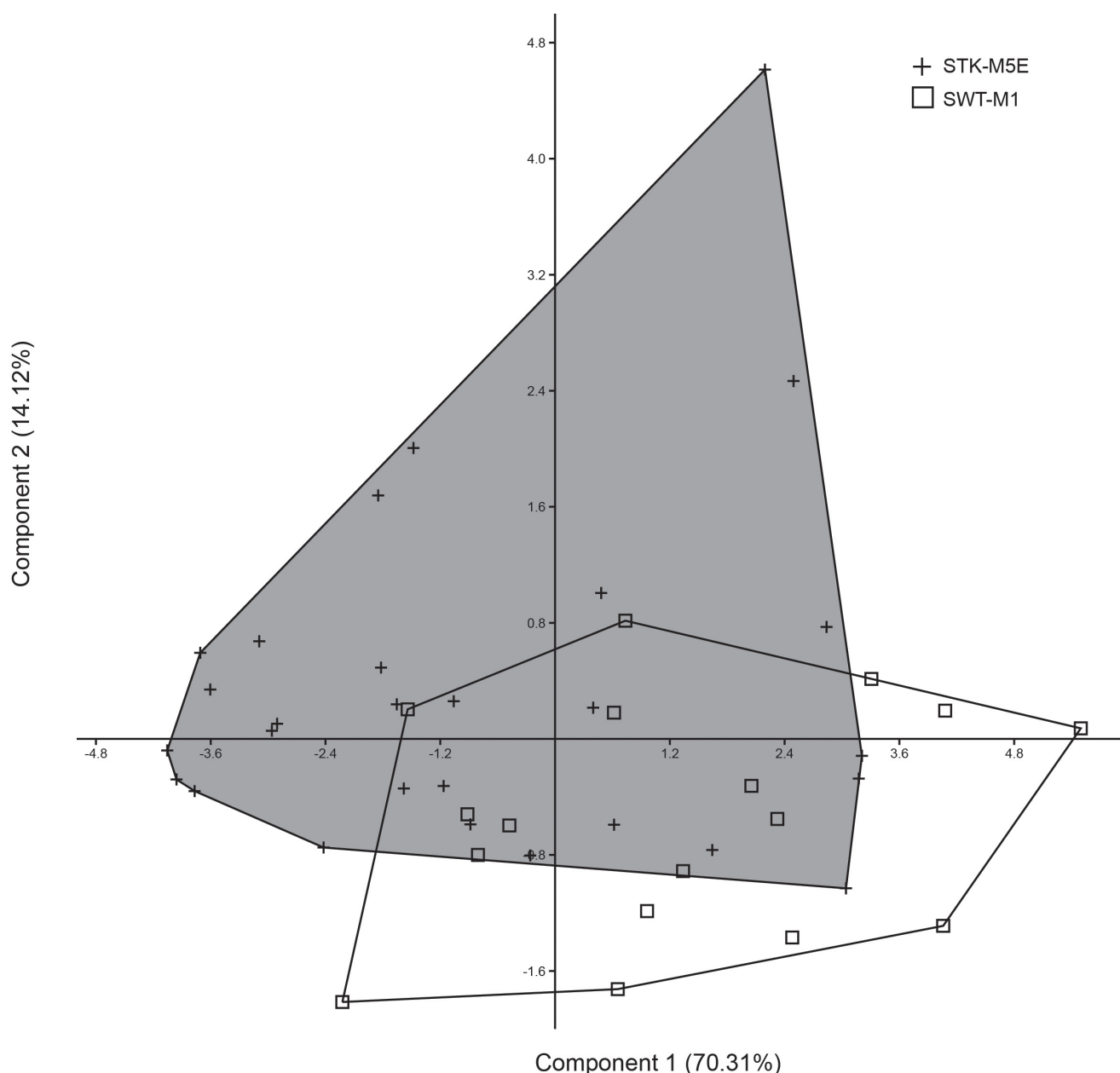


FIGURE 3 PCA scatterplot results showing PC1 and PC2 loadings. Convex hulls (STK-M5E in grey, SWT-M1 in white) outline the extent of the variance of core attributes.

compared to other core types. Further, the regression trend for multifacial cores shows that the SDI is extended relative to increasing sphericity. This suggests a less intensive reduction sequence for unifacial and bipolar knapping methods.

Finally, core types and shape were explored between assemblages. Figure 9 displays boxplots for SDI scores between core types within the STK-M5E and SWT-M1 assemblages. A Wilcoxon Sign Rank test showed a significant difference ($Z = -6.166$, $p < 0.001$) for SDI scores. It is clear that differences in SDI boxplots for STK-M5E multifacial cores, as well as SWT-M1 bifacial and multifacial

cores range significantly above all other core forms. Interestingly, multifacial cores in the STK-M5E assemblage show a long range in SDI values, although this can likely be attributed to a single specimen (#3705) which is unusually large and likely abandoned before it was extensively reduced. Figure 10 shows the relationship between core shape and SDI scores for cores between STK-M5E and SWT-M1, which also confirms earlier trends in reduction strategies. The predominance of spheroidal core shapes is highlighted in both assemblages, although SWT-M1 displays a significantly shorter reduction sequence as cores become more spheroidal. On the other hand, STK-M5E

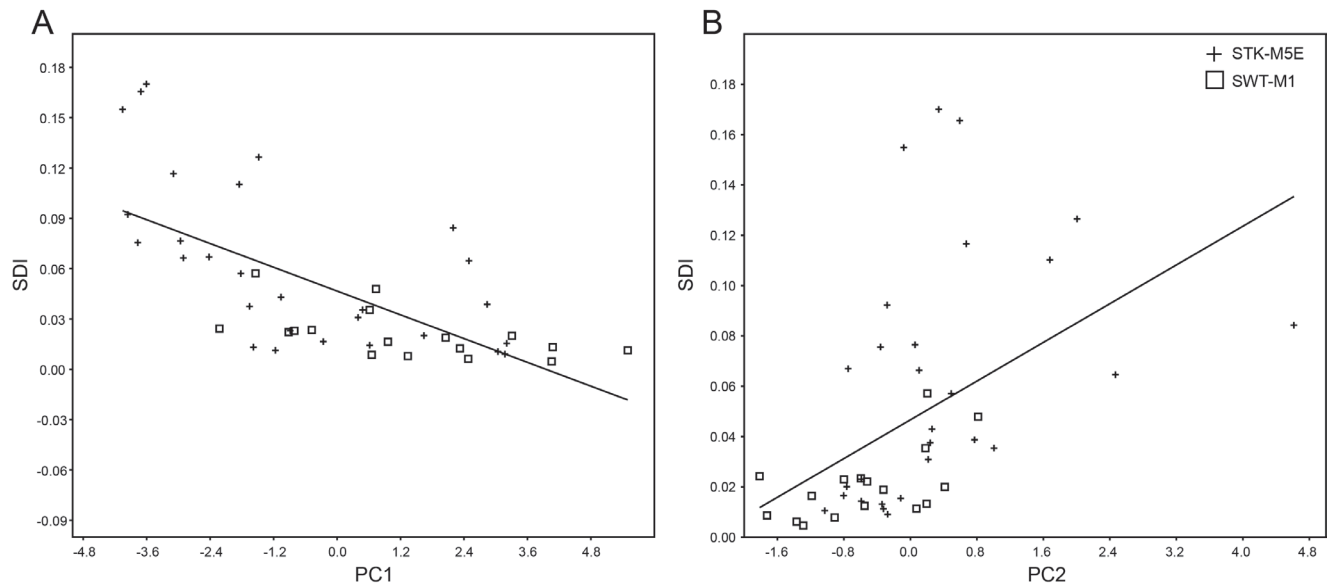


FIGURE 4 Regression comparing PC1 and SDI (A); and PC2 and SDI (B).

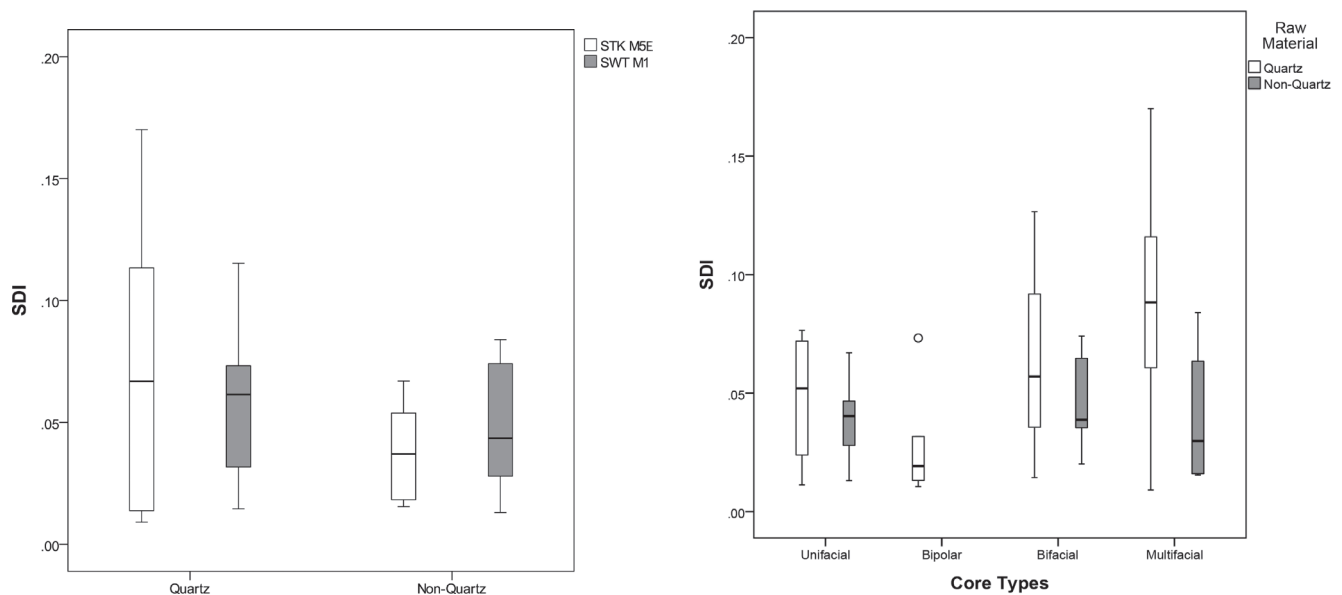


FIGURE 5 Boxplot comparing SDI of cores by raw material groups.

FIGURE 6 Boxplot comparing SDI of cores by typology (○ = outlier).

shows a trends towards a prolonged redcuton sequence, indicating differences in material managment strategies, which is discussed in more detail below.

Cutting Edge Production in Flakes

For the total flake population across all raw materials, Figure 11A shows that UCE values (as a percentage) for SWT-M1 are higher than STK-M5E, which surprisingly contrasts the core reduction findings discussed above. A Wilcoxon Sign Rank test confirmed significant difference ($Z = -8.810$, $p < 0.001$). Furthermore, comparisons between assemblages by raw materials also showed that

non-quartz materials in SWT-M1 flakes were significantly higher in UCE than any other flake category (Fig. 11B). A Wilcoxon Sign Rank test also confirmed significant difference ($Z = -8.910$, $p < 0.001$). Undoubtedly, the small and disproportionate sample sizes within these assemblages have skewed these comparison to some degree, nonetheless these results are worth consideration. Figure 12 displays boxplot results for perimeter (A) and area (B) values between raw materials and assemblages. This shows that SWT-M1 flakes are consistently larger compared to STK-M5, which corroborates higher UCE values in the former assemblage.

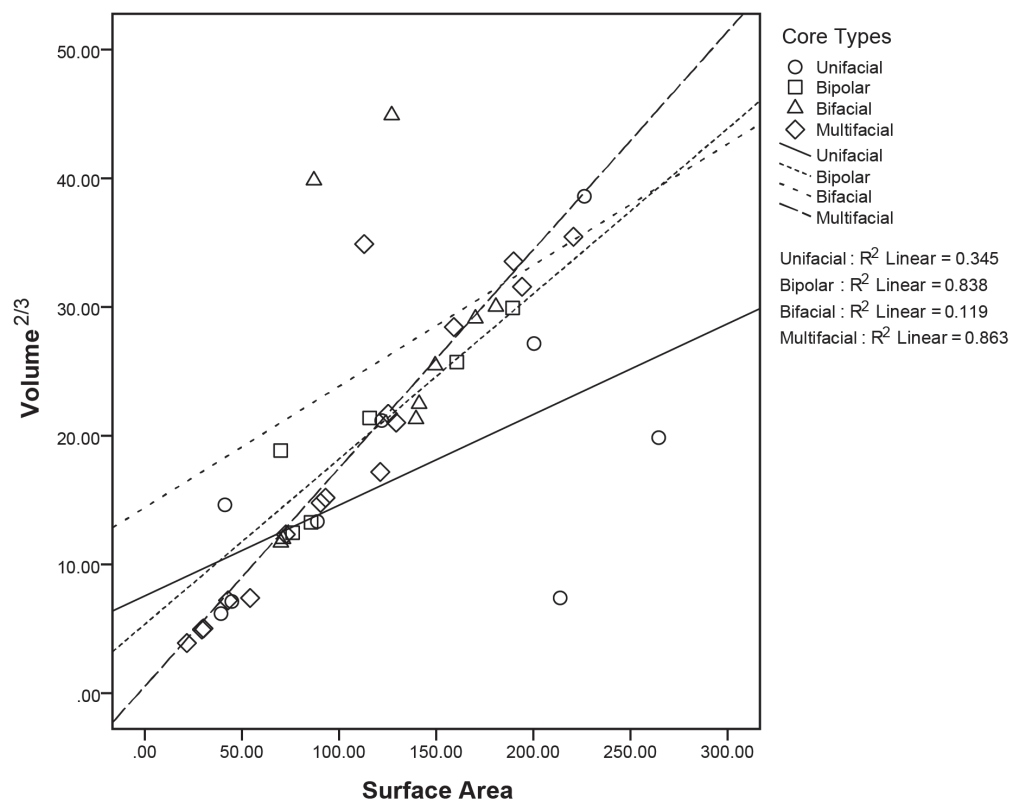


FIGURE 7 Regression comparing $V^{2/3}$ and SA of core types highlighting increasing sphericity in core reduction.

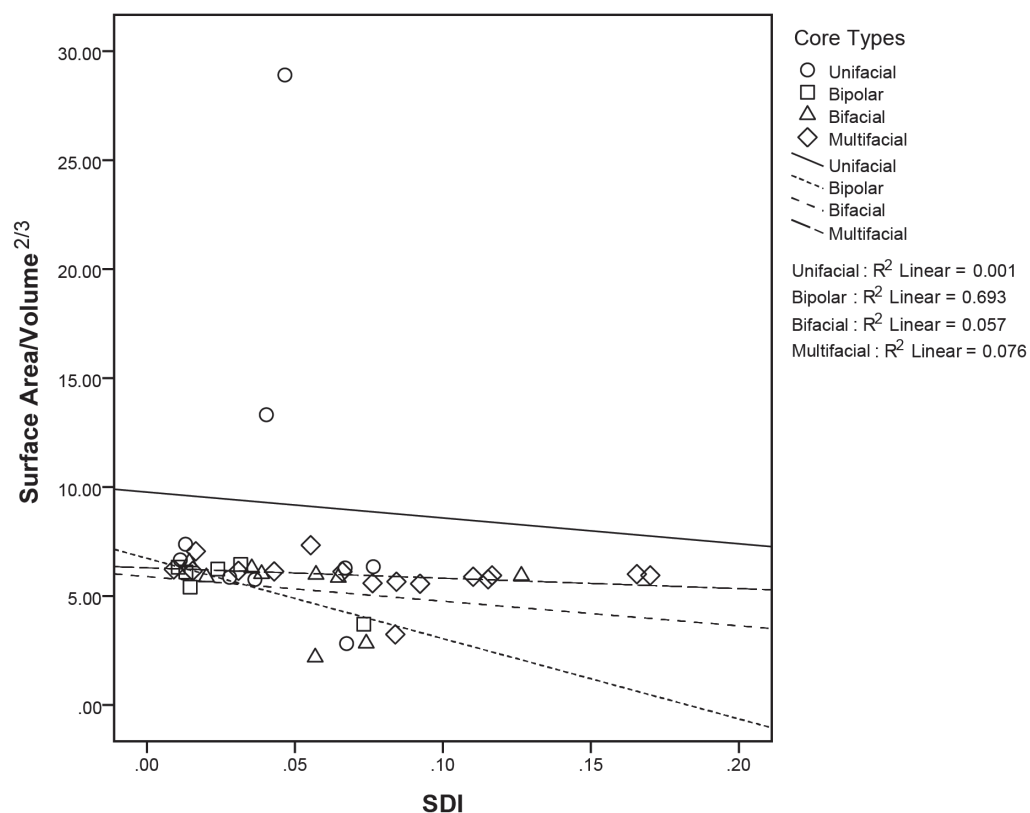


FIGURE 8 Regression comparing $SA/V^{2/3}$ and SDI highlighting the relationship between core types and reduction trajectories.

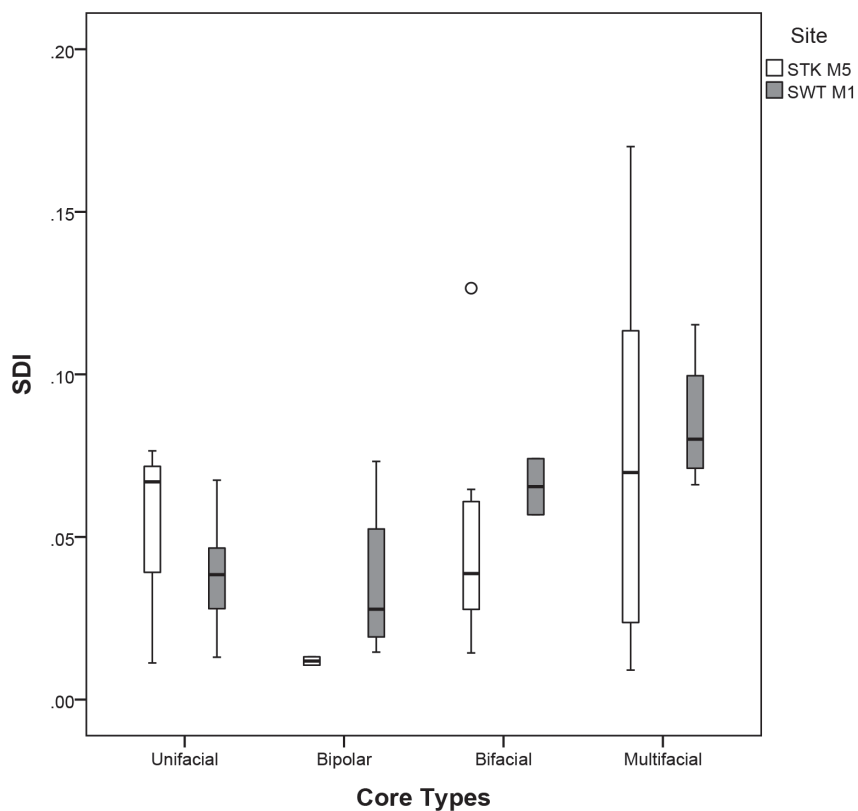


FIGURE 9 Boxplot comparing SDI and core typology indicating increased reduction in multifacial cores (○= outlier).

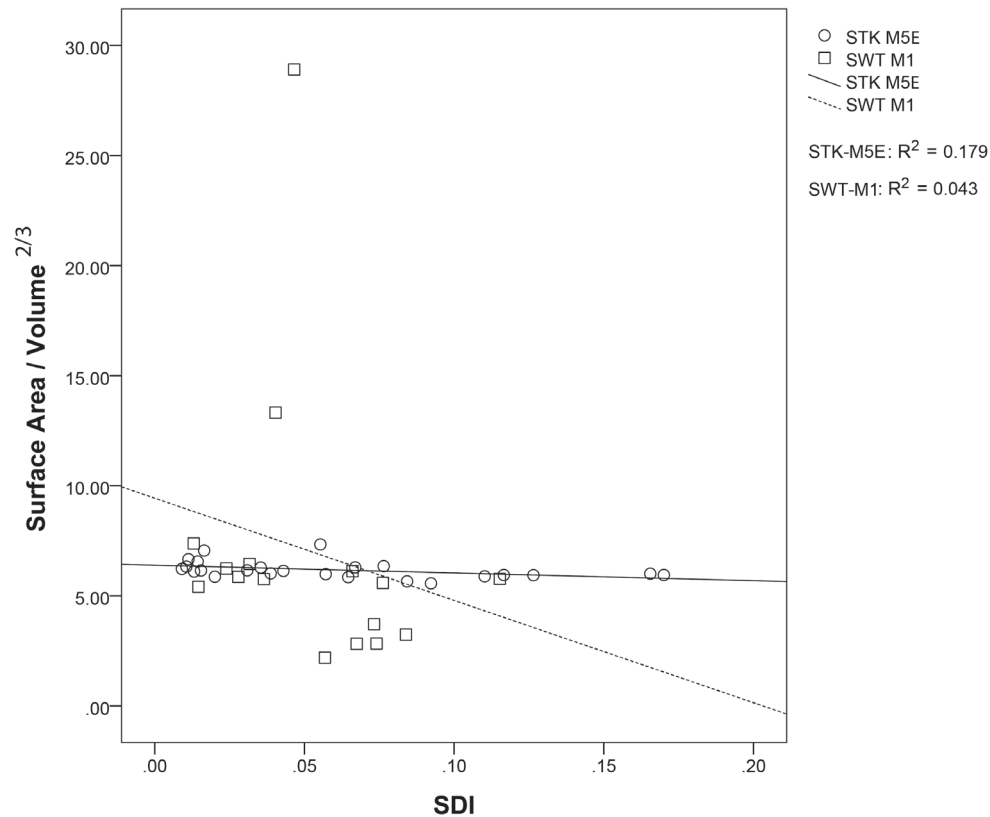


FIGURE 10 Regression graph comparing SA/V $^{2/3}$ and SDI by site highlighting differences in core reduction trajectories.

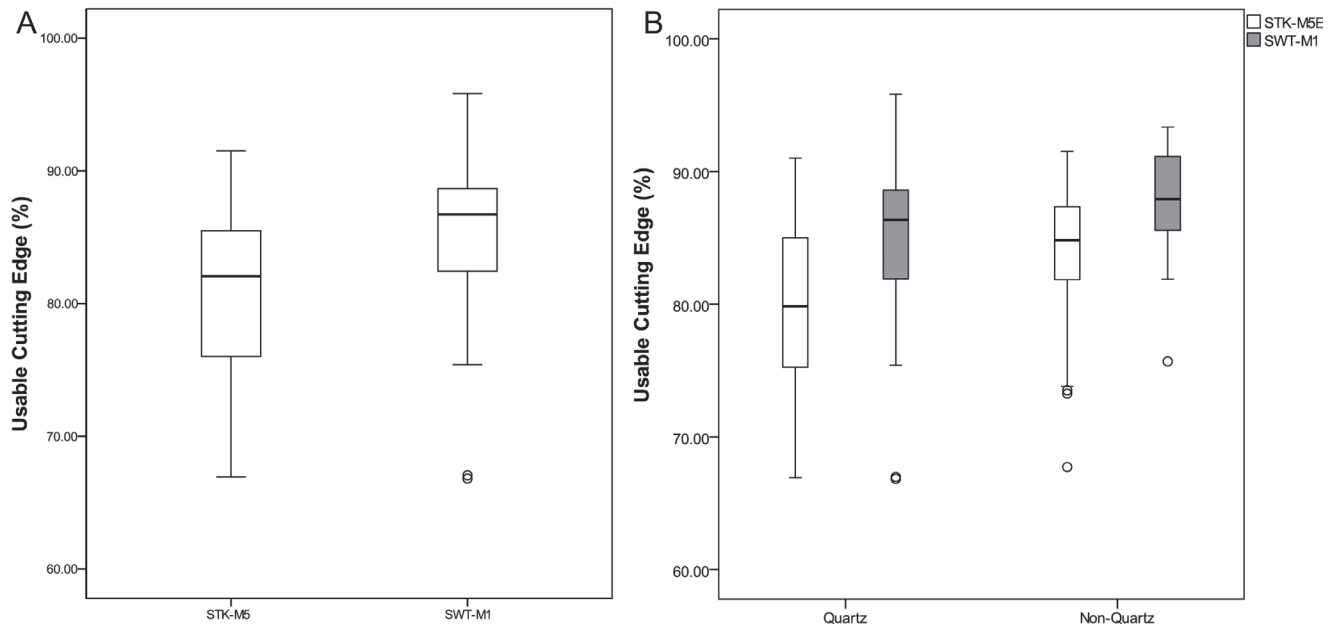


FIGURE 11 Boxplot comparing in whole flakes UCE% by site (A) and by raw materials (B) (○= outlier).

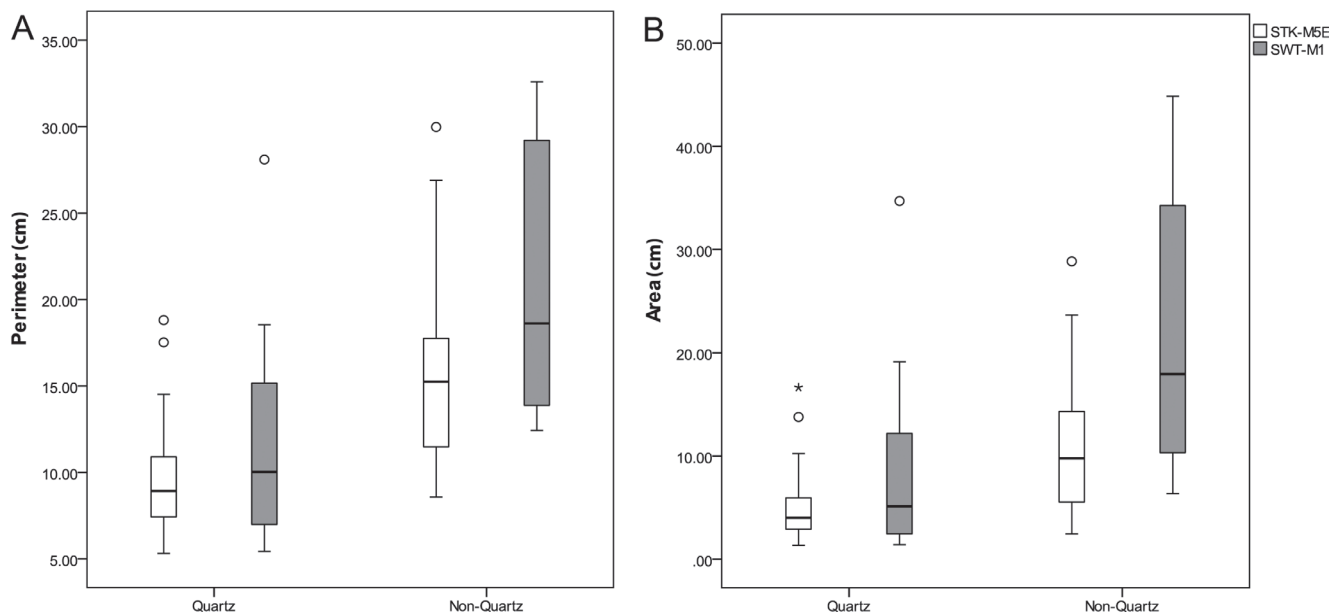


FIGURE 12 Boxplot comparing perimeter (A) and area (B) by raw materials (○= outlier; *= extreme outlier).

Differences in flake size and overall UCE are not easily relatable to core reduction strategies at SWT, although this is a poorly examined relationship in archaeological research (see Prasciunas 2007). As such, experimental research, for instance, determining whether multifacial versus bipolar reduction strategies produce larger flakes is required to determine the effects of reduction methods on UCE. However, in recent research examining the relationship of knapping methods, bipolar versus free-hand on quartz materials have been compared in terms

of cutting edge production by Diez-Martín *et al.* (2012). Their results showed that free-hand methods produce larger flakes, although this was particular to Naibor Soit quartz from Olduvai Gorge. As such, it is possible that the quartz clasts found in the Blaaubank river gravels behave differently when considering their unique formation history (Kuman 1994b). From this perspective, it is possible that bipolar knapping used on quartz from the COH area produces larger flakes. Tallavaara *et al.* (2010) report that bipolar knapping tended to limit the amount of flake

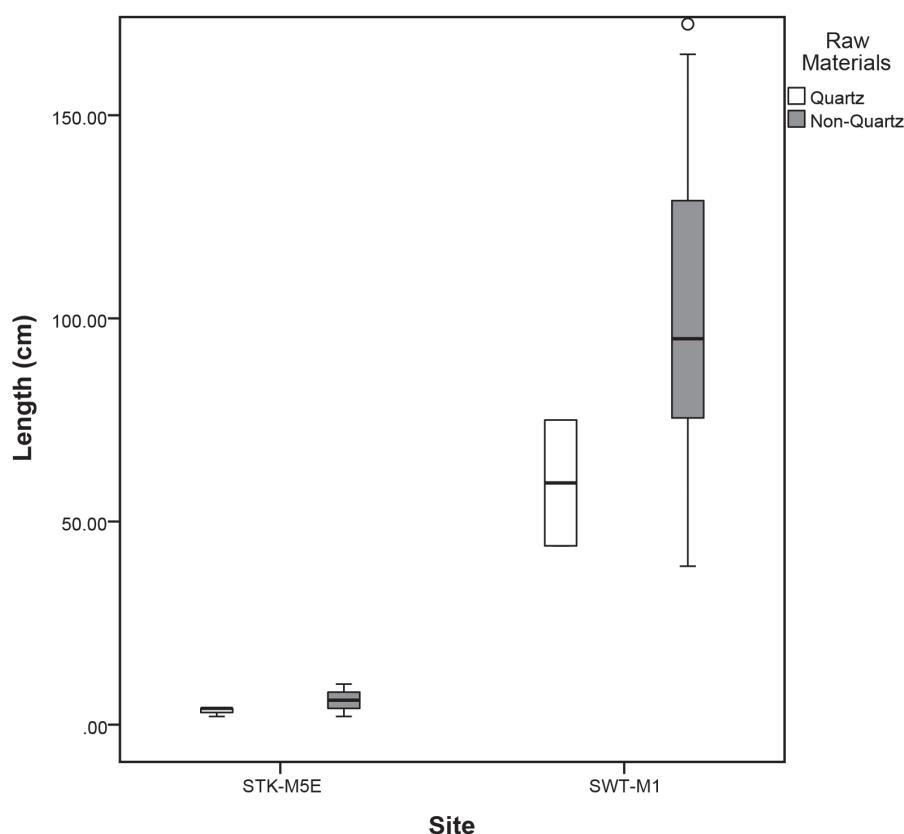


FIGURE 13 Boxplot comparing length of manuports by site according to raw material groups (○= outlier).

breakage during reduction. If this is consistent across different types of quartz materials, the tendency to produce in-tact flakes may also improve the chances of creating larger flakes as seen in the SWT-M1 assemblage.

An alternative hypothesis is that larger flakes simply resulted from the collection of larger clasts used as core blanks. Figure 13 shows a boxplot of manuport length by raw material type, which highlights the increased size range within the SWT-M1 assemblage while the STK-M5E range is relatively restricted (see Kuman & Field 2009). This suggests that core blank selection at STK-M5E was fairly discriminatory. On the other hand, the increased range of SWT-M1 manuport sizes implies less evidence for selection, although this may instead reflect differences in raw material access and/or selection criteria based on production constraints (see below).

Discussion

Package Shape & Core Reduction

Previous research has found that quartz clasts were the preferred toolstone in the COH Oldowan assemblages, al-

though knapping methods employed between STK-M5E and SWT-M1 differ. While both free-hand and bipolar knapping methods are present within these assemblages, bipolar was used more frequently at SWT (Kuman & Field 2009). Also, variability in core types between these assemblages, particularly the increased presence of casual and bipolar cores in SWT-M1, has led to the conclusion that this assemblage represents a more casually-flaked production mode (Field 1999). While this has implications for differences between these sites, further consideration is needed to dissect the relationship between raw material packages and knapping methods. This will provide some insight into lithic production strategies at these sites and the management of materials during core reduction (see Toth 1985).

Table 4 was modified from Field (1999) to show basic raw material package shapes relating to cores and manuports found at both STK-M5E and SWT-M1. Categories for package shapes presented here were limited to those found in the assemblage, although a greater range was found by Field's (1999) survey of the Blaaubank gravels. Three main package shapes identified in the STK-M5E and SWT-M1 assemblages have been described as 'blocky'

TABLE 4 *Raw material package shapes for cores and manuports*

Cores					
STK-M5E (N= 24)	Blocky angular	Blocky rounded	Rounded polyhedral	Indet.	
Bipolar	0	0	2	1	
Bifacial	0	1	0	3	
Casual	0	1	0	1	
Discooidal	0	0	0	1	
Polyhedral	0	0	0	6	
Irregular	1	0	0	5	
Polyhedral					
Single Platform	0	1	0	1	
Total	1	3	2	18	
%	4%	13%	8%	75%	
SWT-M1 (N= 22)	Blocky angular	Blocky rounded	Rounded polyhedral	Tabular disc	Indet.
Bipolar	2	1	0	0	1
Bifacial	0	2	0	1	0
Casual	2	2	1	1	0
Discooidal	0	0	0	0	0
Polyhedral	0	0	0	0	4
Irregular	2	1	0	0	2
Polyhedral					
Single Platform	0	0	0	0	0
Total	6	6	1	2	7
%	27%	27%	5%	9%	32%
Manuports					
STK-M5E (N= 13)	Quartz	Quartzite	Chert	Total	%
Blocky Angular	0	3	0	3	23%
Blocky Rounded	2	3	1	6	46%
Rounded	1	0	0	1	8%
Polyhedral					
Tabular Disc	0	2	0	2	15%
Split-Cobble	0	1	0	1	8%
Total	3	9	1	13	100%
SWT-M1 (N= 21)	Quartz	Quartzite	Igneous	Total	%
Blocky Angular	0	2	0	2	10%
Blocky Rounded	2	9	0	11	52%
Rounded	0	4	0	4	19%
Polyhedral					
Tabular Disc	0	3	0	3	14%
Spheroidal	0	0	1	1	5%
Total	2	18	1	21	100%

(hereafter cubic) in form, rounded and tabular (Kuman & Field 2009). Further, cubic packages have been classified according to their edges as either angular or rounded. It is important to note that cubic package shapes dominate within these assemblages, and are the most common clast form found in the Blaaubank River gravels (Kuman 1994b). Cubic clasts are more voluminous when compared to other package shapes such as tabular forms (proportionally more flat) and how they relate to knapping strategies is behaviourally informative.

Cubic blank shapes are likely to become more rounded as reduction increases, affecting exterior platform angles in that platforms approach 90° faster. Increasing rotation and maximizing exploitable surfaces for flake detachment will thus increase the efficiency of cores. Multifacial knapping is debated as to its level of inherent organization (Schick & Toth 1994; Sahnouni *et al.* 1997; de la Torre *et al.* 2003). However, its dominance in core forms within the COH Oldowan assemblages likely relates to management strategies of cubic core blanks, specifically on quartz materials. As platform angles approach 90° the chance of successful flake removals decreases. Further considering the predominance of quartz materials, high rates of shatter can also prevent successive removals (Kuman 1994b). Therefore, increasing rotation and exploiting multiple platforms in multifacial knapping increases the efficiency of flake production. When analyzing the relationship between core shape and SDI (see Fig. 8), multifacial knapping strategies display increased reduction trajectories when compared to bifacial and bipolar core forms. Thus, as cores become more spherical in shape through increasing reduction (Willoughby 1985), increasing rotation to exploit knappable surfaces increases opportunities for flake removals and ultimately the efficiency of cores. The dominance of multifacial cores within the STK-M5E assemblages therefore demonstrates a pattern between core reduction management and the maximization of flaking efficiency when compared to SWT-M1.

Efficiency vs. Expediency in Flake Production

Furthermore, the production of cutting edge in flakes, operationalized as UCE values also revealed significant differences (see Fig. 11). Cutting edge production shows higher values for SWT-M1 flakes when compared to STK-M5E. In the context of core reduction strategies observed in the SWT-M1 assemblage (see above), these combined results suggest a more expedient reduction strategy. The significance of bipolar knapping within the SWT-M1 assemblage corroborates this interpretation. Gurtov & Eren (2014) found that bipolar knapping on quartz is more

expedient in flake production when compared to other material types (measured as the amount flakes produced per second). However, bipolar strategies have been shown to produce more waste mass during core reduction (Shott 1989; Diez-Martín *et al.* 2011). This implies a trade-off between core management and cutting edge production within the SWT-M1 assemblage. When considering the size range of manuports in the SWT-M1 assemblage (see Fig. 13), unrestricted size selection may also corroborate a more expedient style of raw material collection based on immediate availability of sources.

Previous research comparing core reduction patterns between SWT-M1 and STK-M5E concluded that the SWT material was more casually-flaked, suggesting that this in turn implied 'low cognitive demands' for lithic production (Clark 1993; Field 1999). However, when the results for increased cutting edge production in flakes are considered, core management alone does not reflect cognitive capacities accurately. Alternatively, it is argued here that the SWT-M1 assemblage was more expediently produced due to mobility constraints and the availability of raw materials (see below for discussion).

Considering the above results together for the COH Oldowan, it is clear that differences in lithic production strategies separate STK-M5E and SWT-M1 to some degree. STK-M5E is dominated by the use of multifacial, free-hand knapping techniques, which significantly improves reduction trajectories (see Fig. 8). It can be argued that increasing rotation and the number of exploitable platforms inherent in multifacial knapping methods is a more cost-effective strategy for maintaining flaking efficiency in cores. Considering the extensive use of quartz materials in the COH Oldowan, limiting repetitive percussion on core faces lessens the risk of cores fracturing along internal breakage planes. This would also likely result in less raw material collection efforts. However, the trade-off for this efficiency is a decrease in cutting edge production per flake, although it may be argued that increasing the quantity of flakes through core management is a better strategy for flake replacement when dulling and breakage occurs during tool use. On the other hand, SWT-M1 is characterized by more expedient knapping strategies, although results in larger flakes and cutting edge production. The trade-off here is that cores are less productive as diminished reduction trajectories limit the amount of possible flakes produced per core (see Fig. 10). This would also likely result in a need for increased raw material collection. Overall, the cost-efficiency of flaking at SWT is more expensive in terms of energy and raw material when compared to the opposite trends at Sterkfontein.

Conclusion

Considering why differences in lithic production strategies exist in the two assemblages analyzed here presents some possibilities, although a definitive conclusion requires further investigation. The prevailing theory is that micro-environmental conditions significantly differed between STK and SWT during Oldowan infill times at these sites (Vrba 1988; Reed 1997; Kuman & Clarke 2000; Avery 2001). An increase in water-dependent fauna (i.e. *Hippopotamus* sp.) identified within the SWT-M1 fossil assemblage implies wetter conditions when compared to STK-M5 (Vrba 1988; Reed 1997; Kuman & Clarke 2000). Kuman & Clarke (2000) concluded that the Blaaubank ran closer to the M1 infill entrance at SWT and its likely that gravel conglomerates were plentiful and accessible. In modern times there is a vast exposure of gravels near the base of SWT hill, whereas similar exposures near STK are scarce. While this suggests plausible differences in raw material access, the Plio-Pleistocene geomorphology of the Sterkfontein Valley has yet to be thoroughly reconstructed. Since valleys incise faster than the surrounding hills, it is difficult to determine the reliability of using modern landscapes to predict the gravel exposures at SWT two million years ago. Erosion rates determined through cosmogenics from multiple localities spanning the Plio-Pleistocene are needed to understand changes in the geomorphology of the Sterkfontein Valley conclusively. Recent cosmogenic dating has determined an erosion rate of 5 m per million years associated with STK-M5E (Granger *et al.* 2015) and 3 m per million years associated with SWT-M1 (Gibbon *et al.* 2014). This suggests approximately 6–10 m of land surface has eroded within the last two million years, which is significant considering that the Sterkfontein Valley is shallow (see Fig. 2). However, more data from localities throughout the valley are needed to produce conclusive results on this matter.

Nonetheless, it is possible that the wetter conditions at SWT during Member 1 times created a less hospitable micro-environment. Further, the increased involvement of carnivores in accumulating the SWT-M1 fossil assemblage when compared to STK-M5 may imply increased predation risks for hominin tool-makers (O'Regan 2007). Forbidding conditions near the Member 1 entrance(s) therefore may have constrained production timing. As a result, material collection was limited to local gravel and variability in blank size was related to the random distribution of clast sizes within gravel conglomerates. Larger core blanks, then rapidly reduced through bipolar and free-hand techniques resulted in larger flakes when compared to the STK-M5E assemblage. Another possibility is

that tool-making hominins at SWT purposefully selected larger range of blank sizes to improve their chances of producing useable flakes. The collection of larger clasts may have been in preparation to counter the waste produced through bipolar knapping. This would increase chances of maximizing cutting edge through increasing flake length while production time was limited by environmental factors. By comparison, the increased range of core types (see Table 1) and evidence of core rotation in the STK-M5E assemblage suggests that lithic production was not constrained in the same manner.

In light of previous interpretations focused on the causal nature of SWT-M1 (see above), the results discussed above support expediency and mobility patterns as more parsimonious explanations for differences between the COH Oldowan assemblages. Given they both display similar technological characteristics (i.e. cores and flakes), there seems to be no plausible reason to infer differences in cognitive or behavioral capacities (see Clark 1993; Field 1999). The evidence for core management at STK and cutting edge production at SWT demonstrates that hominins in the Sterkfontein Valley during Oldowan times were proficient tool-makers. Furthermore, if differences in production strategies were environmentally driven, this shows that Oldowan hominin tool-makers in southern Africa were adaptable in shifting production modes according to local conditions at cave sites. This in turn is comparable to patterns detected at Olduvai in terms of distance decay in raw material use (Blumenschine *et al.* 2008) and reduction intensity effects in relation to raw material sources in the Koobi Fora Formation (Braun *et al.* 2008b). Also, the preference for quartz is clearly a selective preference similar to patterns observed in the lower Omo Valley (Delagnes *et al.* 2011). Comparative research between eastern and southern African Oldowan sites is critical for developing a wider perspective on early hominin technological behaviours situated within radically different environments. The patterns brought to light in the South African record further support the adaptive flexibility of early hominin tool-makers and their responsiveness to changing environmental conditions.

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