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Making Points: The Middle Stone Age lithic industry of the Makgadikgadi Basin, Botswana

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ABSTRACT

Studies of early human occupation of Africa over recent decades have profoundly changed how we understand our early ancestors, their inventiveness and adaptability. The spread of *Homo sapiens* to new environmental settings, the expansion of diet breadth, the development of more complex technology and the use of personal ornaments have all been recognized at well-documented Middle Stone Age (MSA) cave and shelter sites, particularly along the South African coast. This paper addresses two under-represented aspects of MSA research: open-air sites and the African interior. We present here recent surveys and excavations in Ntwetwe Pan, Botswana, a remote, open landscape, that formerly contained a vast palaeolake. The five excavated sites yielded assemblages composed exclusively of silcrete, a locally available raw material. The lithic industry at these sites was deposited during dry periods following palaeolake high stands dating to c.128–81 ka and c. 72–57 ka. This industry, characterized by a limited toolkit dominated by highly retouched unifacial and bifacial points, is not previously documented but shows similarities to dated MSA sites of equivalent age in north-western Botswana and Zimbabwe. Combined, these exposed open-air sites document the successful MSA adaptation to a hydrologically dynamic, interior landscape and arguably display MSA behavioural patterns that complement and balance the more well-documented perspectives from coastal cave and shelter sites.

1. Introduction: the under-researched MSA

The spread and characteristics of Middle Stone Age (MSA) archaeological sites in Africa form the basis of our understanding of the development, dispersal, and behavioural range of early *Homo sapiens*. Over the last two decades, this range has radically expanded to include aspects such as abstract art and personal ornaments (e.g., d'Errico et al., 2009; Henshilwood et al., 2002; Henshilwood et al., 2018; Vanhaeren et al., 2019), thermal manipulation of lithic materials (e.g., Brown, et al., 2009), long distance transport (e.g., Ambrose, 2012; Blegen, 2017; Burton et al., 2014; Morgan et al., 2009; Nash et al., 2013a; Nash et al., 2016; Negash and Shackley, 2006; Negash et al., 2007; Wilkins, 2017), complex projectile technology (e.g., Backwell, et al., 2018; Brooks et al., 2006; Lombard, 2011), cooking of starchy foods (Larbey et al., 2019), and structured living spaces, including the use of plant material for bedding (Wadley, 2012). The documentation of expanded MSA diets (e.g., Clark and Kandel, 2013; Jerardino and Marean, 2010), allowing for peopling of ever more diverse landscapes and broader evolutionary niches, has profound consequences for the spread of early humans. However, on a continental scale, archaeological investigations have been heavily concentrated in coastal areas of South Africa, sections of the East African Rift Valley and major cave sites in North Africa. Vast areas of the continent, particularly interior zones with dense vegetative or deep sand cover and/or few caves and rock shelters, remain largely unknown. Notable exceptions include novel investigations in South Africa (Wilkins, 2017), Mozambique (Bicho et al., 2016), Zambia (Duller et al., 2015), Senegal (Scerri et al., 2016) and the Lake Victoria basin, in equatorial eastern Africa (Tyron et al., 2014). The

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concentration of high-resolution and well-investigated MSA sites on the South African coast has led to proposals that these areas saw the first occurrences of important human breakthroughs, such as symbolism or complex hunting technology. It has been suggested that a reason for the correlation of these important findings with coastal environments could be an expanded marine diet, which included shellfish (for an overview see Will et al., 2019). We argue here that our relative lack of knowledge of interior African archaeology is skewing this picture, and that investigations into under-researched areas can provide balance to the current understanding of the interplay between landscape and early *Homo sapiens* behaviour.

This study presents evidence from recent archaeological surveys and excavations of open-air sites in the Makgadikgadi Basin, Botswana, an under-researched and remote area of interior southern Africa. The paper has a particular focus on the previously undocumented lithic industry of this area, and forms part of an interdisciplinary project aimed at understanding how early humans adapted to hydroclimate variability in the late Quaternary Kalahari landscape. This area has locally been known to have abundant Stone Age archaeology (Burrough, 2016; Robbins and Murphy, 1998 and references therein) but has not previously been systematically examined. Further, the Makgadikgadi Basin is a likely route for early migrations across the Kalahari, potentially bridging lithic traditions at the Tsodilo Hills (Coulson et al., 2011; Robbins et al., 2000a; Robbins et al., 2000b; Staurset and Coulson, 2014), in Zimbabwe (e.g., Larsson, 1996; Larsson, 2007), and Zambia (e.g., Barham, 2000; Burrough et al., 2019; Duller et al., 2015), with the more thoroughly documented MSA chronology of South Africa (e.g., Lombard, 2012; Wadley, 2015). Despite the lack of larger archaeological investigations, or even a regional dated chronology for the Stone Age, the Makgadikgadi-Okavango area was recently (Chan et al., 2019) suggested to be the homeland for the founder population of anatomically modern humans, based on modelling of mitochondrial DNA in current human populations (for contrary views see Ackermann et al., 2019; Schlebusch et al., 2019; Thomas et al., 2022).

The series of sites we document here share features that may provide alternate perspectives to MSA behavioural patterns compared to those derived from deep, stratigraphic excavations. They are open-air, partially exposed sites, located on what is now a flat and virtually featureless, seasonally flooded, landscape. This makes it possible to map out sites over large areas, along with potential sources for lithic raw material. It also makes it necessary to consider the impact of site exposure and disturbance, as both factors would potentially influence artefact distribution (Staurset et al., 2022). The transient and, to the modern eye, featureless landscape of the Makgadikgadi pans makes archaeological sites with long-term, repeated use less likely. This limits possibilities for the establishment of archaeological chronologies but opens others for in-depth investigations of MSA behaviours undertaken during shorter timespans. Importantly, the open and highly visible nature of the sites makes total excavation possible during single field seasons. Faced with an abundance of exposed MSA sites, we chose a more horizontal than vertical approach. This involved full excavation of several small and one larger site by *décapage*, and subsequent analysis of the finds with a *chaîne opératoire* approach with an emphasis on refitting. We argue that this methodological approach was essential for attaining the results presented below.

2. Middle Stone Age sites in the Makgadikgadi Basin

2.1. Basin sediments and landforms

The sands, silts and clays of the Makgadikgadi salt pans extend across 16,000 km^2 of northern Botswana, and represent the remnant sump of a former palaeolake system that covered an area of 66,000 km^2 (White and Eckardt, 2006). Today, active feeder rivers include the Boteti, which enters the basin from the southwest, and the Nata and other seasonal rivers that enter from the east. Relative to the surrounding Kalahari landcape, which is characterized by deep sandy deposits that have accumulated since the Pliocene (Thomas, 1988; Haddon and McCarthy, 2005), the Makgadikgadi and its associated fluvial systems are today important zones of net erosion and sediment exposure. During the dry season, the lake muds bake and crack and can frequently form polygonal structures and evaporite crusts that are susceptible to deflation as they collapse (Nield et al., 2015), playing a key role in making the pans one of the largest sources of dust in the southern hemisphere (Vickery et al., 2013).

The two largest pans within the Makgadikgadi complex are Sua (or Sowa) Pan in the east and Ntwetwe Pan in the west, but many smaller pans, also part of the palaeolake basin floor, lie to the south and north. The margins of the palaeolake are demarcated by an impressive escarpment in the south (Stansfield, 1973); a series of horst and graben structures in the north (Eckardt et al., 2016); and broad, sandy beach ridges to the west that predominantly accumulated during lake high stands (Burrough et al., 2009; Burrough and Thomas, 2008). Various features around the palaeolake margins indicate that former high lake stands may have been present for sustained periods of time at 945, 936 and 920 m asl during the late Quaternary (Cooke, 1980; Shaw and Cooke, 1986; Burrough et al., 2009).

The focus in this study is on the sediments and landforms below 920 m asl within the northern and central zones of Ntwetwe Pan. These can be broadly categorised as i) siliclastic lacustrine deposits of mainly detrital quartz and authigenic clays, frequently covered by evaporite crusts; ii) sandy, aeolian dunes overlying the lake bed; iii) vegetated sands deposited both by aeolian and lacustrine processes and elevated several metres above the present-day lake bed. Under current conditions, seasonal rainfall, surface and subsurface flow can flood parts of the salt pan up to a depth of approximately 1 m. As seasonal rainfall or flooding subsides, a shallow water table in conjunction with strong evaporative losses maintains the overall negative water balance. The saline environment within the pan, and the fluctuating pH conditions enable both the ready mobilization of silica from quartz and its re-precipitation as consolidated silcretes, particularly within porous sandy sediments (Nash et al., 1994; Shaw et al., 1990).

2.2. Archaeological surveys

There have been no systematic archaeological surveys of the Makgadikgadi pans (see Coulson et al., 2022 for an overview of previous investigations). However, the current investigation builds upon previous pilot work (undertaken by contributors Burrough and Thomas) in 2008–2009. They noted the considerable extent of Stone Age sites, in particular those attributable to the MSA, across northwest Ntwetwe Pan. The current project examined sites from this pilot investigation, along with those described by local informants, and numerous others not previously reported. Each site was documented in compliance with National Museum of Botswana standards, including a site description, photographic documentation of landscape, artefacts and artefact spread, as well as cultural attribution and an interim assessment of their suitability for excavation. It must be emphasised that, as the current survey was intended to familiarize ourselves with the area and select sites suitable for excavation, it should not be considered a comprehensive overview of all sites in this area. The transitory nature of the ground cover within Ntwetwe Pan can render sites invisible within a matter of weeks. Drying and wetting of silts and clays results in salt crust thrusting, a highly dynamic process (Nield et al., 2015) that can create an elevated ridged surface over denser subsurface sediments covering otherwise visible artefacts. An exhaustive survey of this area would likely require years, in order to do justice to the abundance of hidden and semi-covered sites.

The focus of this project was northern and central Ntwetwe Pan, its pan floor and localized landforms. We surveyed this area of the pan, along with the Boteti and Nata Rivers and smaller pans to the south of Ntwetwe (Coulson et al., 2022). Approximately three weeks each in 2016 and 2017 was devoted to this survey, with roughly half the time devoted to the pan floor and shore areas. Beyond the present-day pan margin and along the rivers, denser vegetation and net sediment accumulation in the Holocene (Burrough et al., 2022) rendered sites far less conspicuous than the open pan floor, where artefacts in black silcrete were highly visible against the exposed, white salt encrusted, former lake bed. It quickly became apparent that surface clusters of lithics were abundant, particularly on the pan floor (see Fig. 1). Another unexpected factor was the importance of the angle of light at the time of survey, which made perceptible sites extremely hard to see if the sun was behind the viewer. Due in part to the generally high visibility of the sites, test pits were deemed unnecessary. The extent of the survey was affected by several factors, including variable water levels, vegetation, and occasional restricted access. As a result, there is a bias towards sites located in the northern parts of the pan and those close to existing tracks and the present-day pan margin and former lake edges. Despite these minor caveats, the open nature of the pan and the contrast between ground cover and artefacts proved extremely well suited for locating a large number of archaeological sites (see Coulson et al., 2022). The limited access to and restricted modern development of the pans provided a vast area with potential for minimal modern disturbance.

As can be seen in Fig. 1, most of the sites were recorded on the pan floor (examples in Fig. 2). Exposed archaeological sites have a reputation for poor site preservation and have often not been considered worthy of in-depth investigation. We located several large scatters that matched this reputation: wash zones with jumbled evidence of diagnostic artefacts from several archaeological periods stretching hundreds of metres. Smaller scatters strongly affected by erosion caused by wind or water were also common. However, we also located numerous sites, of variable size, where there was no visible disturbance, and the extent of the artefact distribution was still clearly visible. In several cases knapping scatters could be tentatively identified during survey, and refits made between lithics located less than 1 m apart. There was no apparent geographic pattern as to where these less disturbed sites occurred. Given the long and hydrologically active history of the pans, it is however likely that some sites could have been exposed and re-covered on multiple occasions and been affected by a number of landscape features that are no longer visible (see Burrough et al., 2022, for further evidence and a detailed discussion). However, two key features of the sites that appeared more or less intact are notable – they were: i) frequently adjacent to overlying Holocene dunes (or evidence that dunes formerly occupied the area), landforms that may have protected the underlying sediments from deflation (Burrough et al., 2022); and ii) often located next to areas with large hardened clay surfaces, which potentially could have helped keep artefacts more stable than less consolidated areas of the pan floor. Universally, knapping debris <7 mm length was not present on the sites and is presumed to have succumbed to the abovementioned erosion. Animal tracks also cross the modern pan surface and are likely to have modified artefact location and depth. We did not locate any sites that appeared completely pristine or undisturbed (Staurset et al., 2022); rather the level of disturbance varied on a very wide scale. It should be noted that on the present-day pan floor, which undergoes large seasonal hydrological changes, dominant landscape features that could promote repeat visits by hunter-gatherers to the same location are scarce. This may have resulted in a larger percentage of single-use or ephemeral sites compared to more stable landscapes dominated by prominent landscape markers such as hills or rivers.

Beyond the northern margins of Ntwetwe Pan, the condition of sites was markedly different. Here, the artefacts were located in loose, sandy deposits, or embedded in calcrete formations. These scatters were clearly disturbed by modern habitation, ranching and elephants. In most cases the limits of the scatters were diffuse and often overlapping with others. In addition to the pan area itself, we surveyed along the Boteti River westwards to Maun and various smaller pans along the southern edge of Ntwetwe. These areas presented very different landscapes and archaeology, which are explored in Coulson et al. (2022).

Given the substantial number of archaeological concentrations and their variable quality, we divided these into sites and scatters (see Fig. 1). A *site* refers to locations where artefact concentrations are of clearly limited extent, have few indications of disturbance and consistent levels of artefact weathering and condition. These ranged in size from c. 25 m^2 to more than 5,000 m^2 and appeared promising for future investigations. A *scatter*, in contrast, signifies a blurred spread of archaeological material, often comprising varied levels of weathering, often jumbled, mixed and size sorted. Old shorelines and heavily eroded distributions fall into this category, regardless of size. Some examples of sites and scatters can be seen in Fig. 2. One pan floor area of c. 250 × 600 m had such a density of artefact concentrations in close proximity that we designated the area MAK14 and further subdivided by letters into 15 separate sub-areas; two of these sub-areas were later excavated (MAK14K and MAK14O, see Fig. 1 and below). In addition to the sites and scatters we located numerous loose, single finds of diagnostic artefacts, retouched MSA tools and exhausted cores. These are features which will NOT be indicated in Fig. 1.

The vast majority of recorded sites fell securely within an MSA framework, based on technology and the characteristic, highly retouched, points common to the Kalahari (Coulson et al., 2022). All the lithic raw material at MSA sites was silcrete, and the artefact concentrations were often located close to or on top of natural occurrences of this material. The MSA sites and scatters documented beyond the north-western margin of Ntwetwe Pan comprised significantly more expedient technology, with fewer retouched tools. These were often located directly on top of silcrete/calcrete occurences. Sites with diagnostic artefacts from the ESA, LSA and Iron Age were also present and are discussed in Coulson et al. (2022), and associated chronologies presented in Burrough et al. (2022) and Thomas et al., (2022). None of the surveyed sites had preserved faunal remains but given the presence of fossilized bone on the pan floor there is potential for the discovery of such sites.

2.3. Excavated sites

Given the predominance of sites attributable to the MSA, this period was the primary focus for sites selected for more intense investigation. To the best of our knowledge this is the first time sites have been excavated on Ntwetwe Pan, meaning we had no prior knowledge of the vertical aspect of the sites (also see Coulson et al., 2022). Through the excavations we aimed to acquire enough archaeological data to 1) classify and understand the predominant MSA industry; 2) investigate the technology and techniques used in its production; 3) determine whether these factors varied greatly from site to site; 4) provide lithic samples for geochemical

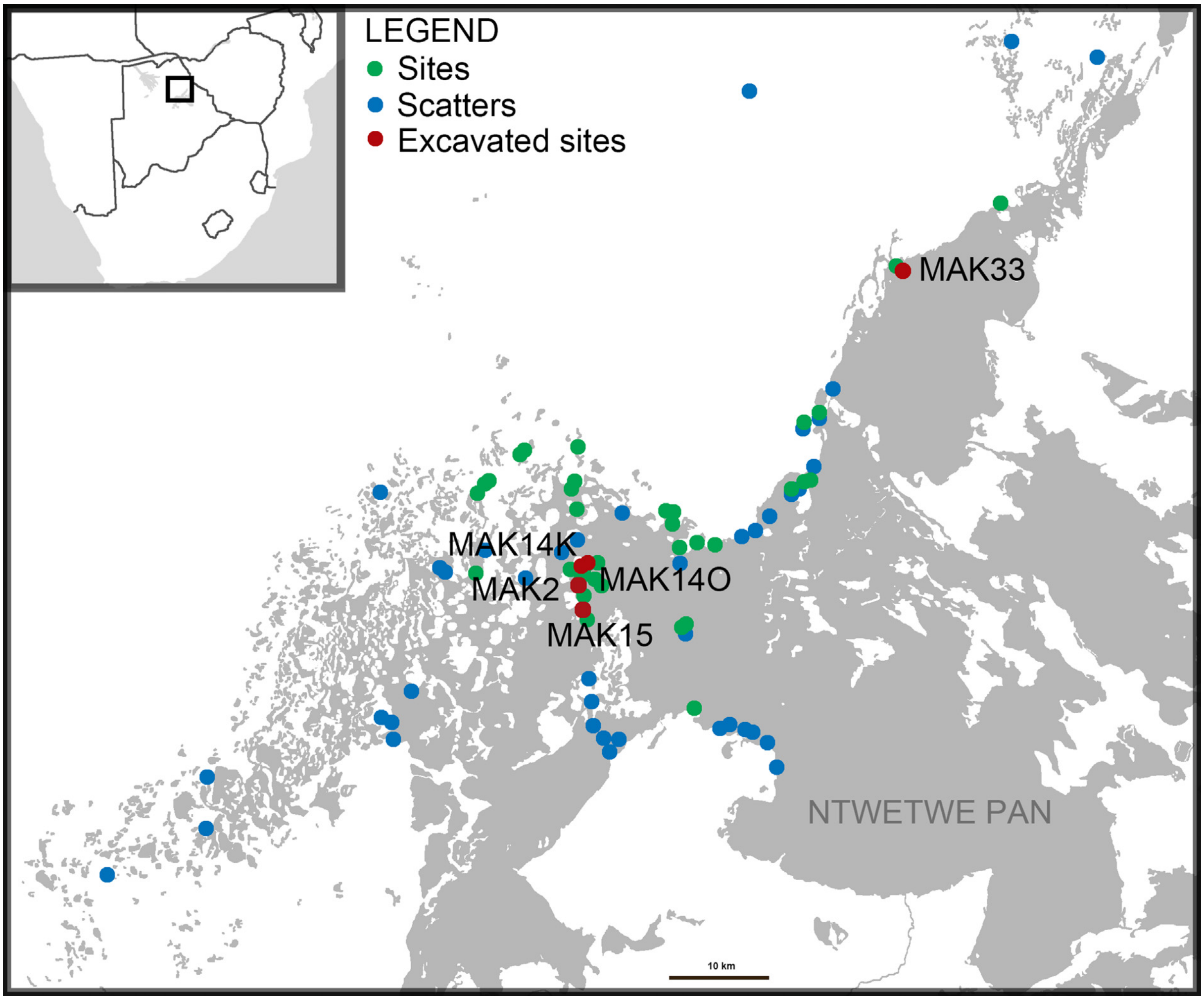

Fig. 1. Distribution of recently surveyed and excavated archaeological sites and scatters in the Makgadikgadi Basin.

provenancing reflecting the material chosen for prehistoric production (as reported in Nash et al., 2022); 5) represent sites associated with different landscape features in the pan environment; and 6) determine the timing of site deposition and its relation to palaeohydrological conditions in the basin via optically-stimulated luminescence (OSL) dating (see Burrough et al., 2022). To achieve these goals, we began by excavating four smaller sites (MAK2, MAK14K, MAK14O and MAK15) and, based on experience with the uncovering of these, moved on to incorporate one large site (MAK33, location of all sites shown in Fig. 1). In conjunction with goals 1–4 listed above we prioritized sites with limited indications of post-depositional disturbance (erosion, vehicle tracks, trampling by animals, differential weathering, etc.) where the lithic spread was clearly delineated and of a size feasible for excavation within a period of approximately five weeks total. As the extent of the sites could be roughly estimated due to their exposed nature, it was possible to aim for full excavation in every case. We also prioritized sites where several stages of lithic production were evidently present. To address goal 5, we factored in sites associated with dune edges, hardened clay areas and silcrete outcrops, and, for goal 6, those with higher potential for dating (see Burrough et al., 2022; Nash et al., 2022; Thomas et al., 2022). OSL dating at MAK14K, MAK14O, MAK15 and MAK33 (reported in detail by Burrough et al., 2022), revealed that the lithic industry at these sites was deposited during dry periods following palaeolake high stands dating to c.128–81 ka and c. 72–57 ka.

Given the exposed nature of the sites, they were especially well suited for *décapage* excavation rather than random squares or trenching. In these conditions the first step of removing the overburden equated to brushing off the scant loose deposit that partially covered the site surface. A grid of 1 m^2 squares was established at all sites, further subdivided into 50 × 50cm quadrants. Exact plotting of artefact pieces and their angle of orientation was not attempted as some post-depositional disturbance was expected due to the open nature of the sites. Each quadrant was photographed before and after every stage of removal so that identification of individual locations was possible. The grid covered all visible concentrations, and extended beyond the excavated area, where it was used to register surface collected artefacts.

After the loose surface deposit was removed and the entire site uncovered, each square was individually documented. The artefacts were lifted, listed and bagged by quadrant. A 5 cm layer was then removed, leaving any previously concealed artefacts in place. In most areas deeper excavation was impeded by layers of hardened clay. Where we could go deeper, the revealed surface was documented, and artefacts lifted following the same steps as the surface layer. All removed deposit was sieved through a 3 mm mesh. At all sites, the number of below-surface finds was extremely low, at MAK33 < 0.5% of the assemblage (see Staurset et al., 2022 for details). We also tested below 5 cm in areas of dense artefact

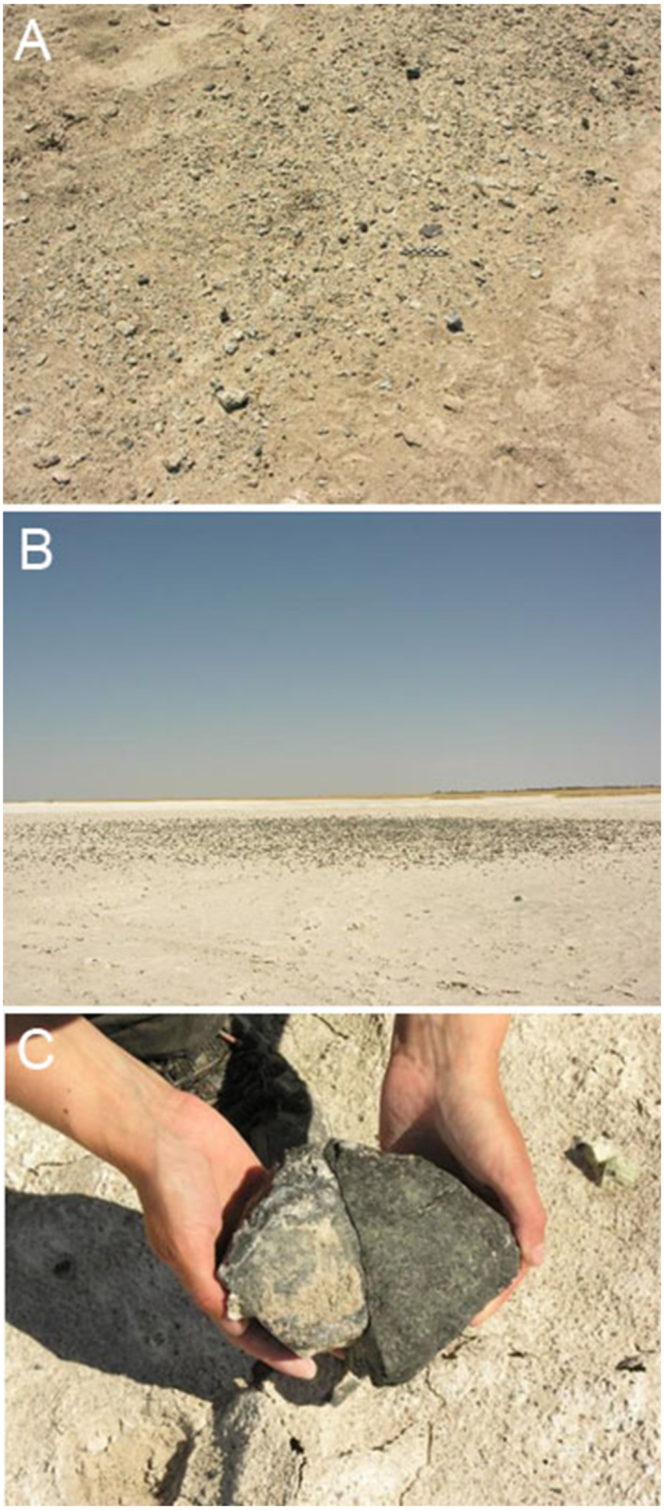

Fig. 2. Examples of archaeological sites and scatters in and around northern Ntwetwe Pan. A) Archaeological scatter disturbed by flowing water (MAK27). B) Highly visible concentration of artefacts and natural pieces in black silcrete against the salt-encrusted silt pan floor (MAK34). C) Refit testing of site integrity during survey (MAK29).

concentrations, which confirmed this impression. At each site, some squares were dug to much deeper layers (typically 0.5–1 m) for sampling for dating and sedimentary analysis (see Burrough et al., 2022 for details). Only one of these deeper pits uncovered a potential MSA flake (at site MAK33). This was found approximately 35 cm below the pan surface and is considered to be *in situ* but unrelated to the excavated section of MAK33 presented here.

These investigations confirmed the two-dimensional nature of the Ntwetwe sites, which contrasts sharply with the deeper, sandy MSA sites previously excavated at Tsodilo Hills or ≠Gi Pan in northwest Botswana (see Section 4.1 for detailed descriptions). They also confirmed that the surveys were accurate in determining plausible site dimensions. The shallowness of the archaeological layer meant that it was possible to excavate several hundred square metres in a matter of weeks and uncover entire sites (overviews can be seen in Table 1 and Fig. 3). We began by investigating site MAK14K, a small concentration of MSA debris and tools ($n = 88$) spread roughly parallel to the edge of a small dune. A single flake was recovered underneath the dune, indicating the site was older than this landscape feature (also see Burrough et al., 2022). Investigations continued at nearby MAK14O, a denser and larger artefact spread ($n = 555$) located close to several hardened clay surfaces elevated c. 5–20 cm relative to the surrounding pan floor. In addition to debris, tools and cores, we recovered several large blocks of black silcrete with limited knapping scars, indicating that more stages of lithic tool production had taken place at this site. To further investigate the relationship with existing landscape features, we then excavated two smaller sites, MAK2 ($n = 38$) and MAK15 ($n = 55$), both located along dune edges. At each site, a single flake was recovered beneath the dune edge, at the same level as the artefacts exposed on the surface. The lithic assemblage at both these sites appeared more haphazard. Several large bifacial MSA points were recovered, neither of which appeared related to the debris from each site, both in terms of raw material and technology.

Based on our experience with these sites, we devoted the second and final field season to fully excavate one larger MSA site, MAK33 ($n = 3426$), to gather sufficient lithic data for in-depth analysis of on-site lithic production and behaviour (see Fig. 3). The MAK33 assemblage forms the core of our description of the Makgadikgadi MSA industry outlined below. The site itself was located on the open pan floor, partially on top of a low silica/clay hardground. A few MSA artefacts were encrusted and/or embedded in this hard matrix, indicating that its formation at least partially postdates MSA use of the site (see Staurset et al., 2022 for an illustration of this feature). The excavated area included several potential knapping areas. A second, large concentration was recovered by surface collection in the wetter, softer deposit to the east. We incorporated these artefacts into the 1 m^2 excavation grid, and extended surface collection around the site to more than 4,000 m^2 in total. The interaction between these areas and the significance of deposit and post-depositional disturbance are discussed in Staurset et al. (2022). After excavation all artefacts were transported to the National Museum in Gaborone, where they were analysed and subsequently entered into the museum collection.

2.4. Methodological approach: chaîne opératoire with emphasis on refitting

A multitude of approaches to lithic analysis have been used in MSA research. One standard is the *chaîne opératoire*, which is now commonplace also in southern Africa (e.g., de la Peña and Wadley, 2014; Lombard and Högberg, 2018; Porraz et al., 2013; Rigaud et al., 2006; Soriano et al., 2015; Sumner and Kuman, 2014; Will and Conard, 2016). A *chaîne opératoire* framework requires an in-depth "reading" of archaeological material (e.g., identification of raw material, production techniques and methods; classification according to stages of manufacture as well as post-production modifications; distinction of artefact types, etc.), prior to interpretation (Pelegrin, 1990). Traditionally applied to lithic assemblages,

Table 1
Overview of the five excavated MSA sites in Ntwetwe Pan, Botswana. Note that in addition to the excavated area a larger surrounding zone was surface collected at each site using the site grid. The artefact condition is based on the level of weathering, as classified by Bustos-Pérez et al., (2019: Table 15).

Site name	Setting	Excavated area (m^2)	Total number of lithics	Main modes of core reduction	Number of main raw material groups	Main products	Artefact condition (level of weathering)
MAK2	Edge of small dune	24	38	Laminar (?)	3	• Points (late stages only)	Very fresh
MAK14K	Edge of small dune	42	88	Levallois, discoidal, Kombewa	3	• Points • Core preparation	Fresh to mint
MAK14O	Pan floor	100	555	Levallois, Kombewa, discoidal	13	• Points • Blanks • Core cleaning and preparation	Very fresh
MAK15	Edge of low, elongated dune	22.25	55	Levallois, laminar	4	• Points (late stages only) • Blanks	Very fresh
MAK33	Pan floor	430	3426[1]	Levallois, two platform	14	• Points • Blanks • Knives • Core cleaning and preparation	Very fresh to mint

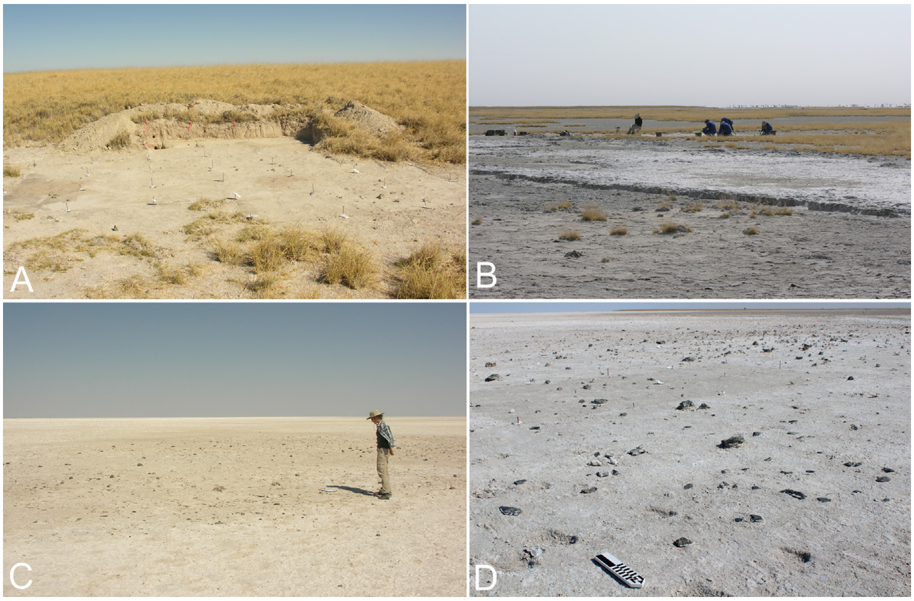

Fig. 3. Middle Stone Age excavations at Ntwetwe Pan. A) Site MAK15 after excavation, edging into the small dune in background. B. Site MAK14O under excavation. Note hardened clay surface in the foreground. C) MAK33 prior to excavation, showing the spread of dark silcrete artefacts on the pan floor. D) Visible artefact concentrations at MAK33 after cleaning of surface. Note zebra tracks next to the North arrow.

use of this approach is now widely applied to other materials such as pottery, bone tools or site features such as hearths. Like other qualitative methods of analysis inspired by anthropology, *chaîne opératoire* investigations can be adapted to local conditions and research questions. Common elements include refitting (e.g., Coulson, et al., 2011; Dietl et al., 2005; Högberg and Larsson, 2011; Kandel and Conard, 2013; Marean et al., 2000; Porraz et al., 2013; Sumner, 2013; Texier et al., 2013), experimental replication (e.g., Backwell, et al., 2008; Barham, 1986; Bentsen, 2007; Dayet et al., 2013; de la Peña and Wadley, 2014; Lombard et al., 2004; Pargeter, 2007; Schmidt et al., 2013; Wadley et al., 2009; Zipkin et al., 2014), usewear (e.g., Igreja and Porraz, 2013; Langejans, 2012; Lombard and Wadley, 2009; Wadley and Langejans, 2014) and reconstruction of artefact biographies (e.g., Porraz, et al., 2013; Schmid, 2019; Schmid et al., 2019; Soriano et al., 2015; Wilkins, 2018). We chose a *chaîne opératoire* approach with strong emphasis on refitting and reconstruction of reduction strategies for two main reasons. Firstly, it provides a gateway into understanding hitherto undocumented production processes starting with individual raw material blocks. Secondly, the complete excavations gave us the opportunity to explore a full set of lithic MSA behaviours, as opposed to assemblages from partially excavated or trenched sites. This opens opportunities for understanding the norm for how much debris is produced on MSA sites, and a more representative reconstruction of site behaviour than deeper excavations of lesser horizontal extent. We also hoped to contribute to the development of methods suitable for analysing similar exposed lithic assemblages.

As indicated by numerous researchers (e.g., Conard, et al., 2012; Douze et al., 2015; Lombard and Högberg, 2018; Porraz et al., 2013; Soriano et al., 2015; Villa et al., 2010), the plethora of approaches to lithic classification and analysis in Africa underlines the necessity

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[1] This number includes a characteristic raw material group (M) with a tendency to produce shatter ($n = 775$), on which very little refitting was attempted.

for thorough descriptions of the analytical methods and nomenclature used. We will give a brief overview of the former here; the latter will be addressed through in-text definitions. The following stages were used for the lithic analysis of all the excavated materials. In preparation for study, all the materials were cleaned and labelled. In some cases at MAK33, the encrusted sediment, similar to the local silica/clay hardground, was so hard that it could not be removed. Using procedures developed with silcretes from northwest Botswana (Nash et al., 2013a; Nash et al., 2016), the assemblage was then divided into raw material groups based on hand specimen characteristics (i.e., fracture pattern, grain size, degree of cementation, level of translucence, type of cortex, the presence of rinds, patches, or specks). Colour was found to be less reliable for separating artefacts into their respective knapping groups, as most of the lithics were dark grey to black silcrete and many blocks included bands in various shades of grey. The raw material groups were continually refined and reassessed during the entire analysis and refitting process, as many blocks displayed similar characteristics (for an overview, see the Supplementary Online Material in Staurset et al., 2022). These groups were later used as the basis for selecting samples for geochemical provenancing (see Nash et al., 2022).

The objective for separation into raw material groups was to identify artefacts that likely originated from the same block of raw material. These formed the starting point for the refitting investigation. Refitting necessitates the identification and memorization of a wide set of characteristics within a body of material, a process through which one also gains a thorough understanding of its *chaîne opératoire*, and further permits interpretations even of the lithic material that was not refitted (Coulson and Andreasen, 2020:5). Thus, the refitting and technological classification of the assemblage becomes more of an interactive process, as understanding of the local technology and raw material increases (Soressi and Geneste, 2011). The refitting study was conducted by two researchers (contributors SS and SC) over a combined total of 10 weeks, at which point it was still producing new results. The MAK33 assemblage was prioritized, as it comprised the largest data sample, with nearly all *chaîne opératoire* stages present. We targeted the raw materials groups with the most complete production sequences. The extensive refitting forms the basis for assessing post-depositional disturbance at the Makgadikgadi sites, which is further explored in Staurset et al. (2022). MAK14K and MAK14O, which initially appeared to be prime candidates for extensive refitting, yielded surprisingly few results. At MAK33 however, c. 21% of the assemblage could be refitted. During this analysis, the location of each artefact was disregarded, so that raw material grouping, refitting and technological classification was not influenced by its position on site. This was done to lessen bias towards refitting of pieces located close together, which can affect interpretation, particularly of post-depositional movement (e.g., Cahen and Moeyersons, 1977; Cahen et al., 1979; Cahen, 1987; Close, 2000; Hofman, 1981; Hofman, 1986; Hofman, 1992; Staurset and Coulson, 2014; Vaquero et al., 2017; Villa, 1982). Artefacts were also recorded in a database by unit, raw material group and technological stage. Pieces of special interest (e.g., cores, retouched tools, preferential flakes) were measured and photographically documented.

2.5. Lithic raw materials and artefact condition

The Makgadikgadi MSA lithic assemblages are exclusively made in silcrete, an observation which was confirmed at all the surveyed sites in Ntwetwe from this period (examples in Fig. 4). Silcrete, a fine-grained, silica-cemented raw material common throughout southern African prehistory (e.g., Brown, 2011; Högberg and Larsson, 2011; Mackay, 2008; Marean, 2010; Minichillo, 2006; Mourre et al., 2010; Nash et al., 2019; Nash et al., 2016; Porraz et al., 2008; Schmid, 2019; Schmidt, 2017; Stolarczyk and Schmidt, 2018; Villa et al., 2009; Will and Mackay, 2017; Wurz, 1999) is also used at other Kalahari MSA sites, albeit often in conjunction with chert, quartz and/or quartzite (e.g., Coulson, et al., 2011; Helgren and Brooks, 1983; Robbins et al., 2000a; Robbins et al., 2000b; Staurset and Coulson, 2014). Importantly, analyses of trace element composition has made it possible to provenance archaeological Kalahari silcrete to original source areas (Nash et al., 2013a; Nash et al., 2013b; Nash et al., 2016), providing possibilities for the reconstruction of MSA movement patterns. This facet of Makgadikgadi MSA behaviour is further discussed in Nash et al. (2022). Silcrete outcrops occur regularly within and along the current edges of the Makgadikgadi pans (Nash et al., 2022 and references therein). The fragmented, natural blocks of silcrete located at pan basin outcrops appear similar to most of the raw material blocks used as cores at Makgadikgadi MSA sites. The selected tabular blocks vary in thickness from c. 3–20 cm, presumably determined by the thickness of the source silcrete outcrop. This means that most core reduction sequences start with a tabular block with two weathered, opposing surfaces. The silcrete ranges in colour from black to almost white, with occasional shades of brown or green (examples of different silcrete varieties can be seen in Fig. 4). However, both colour and other hand specimen characteristics can

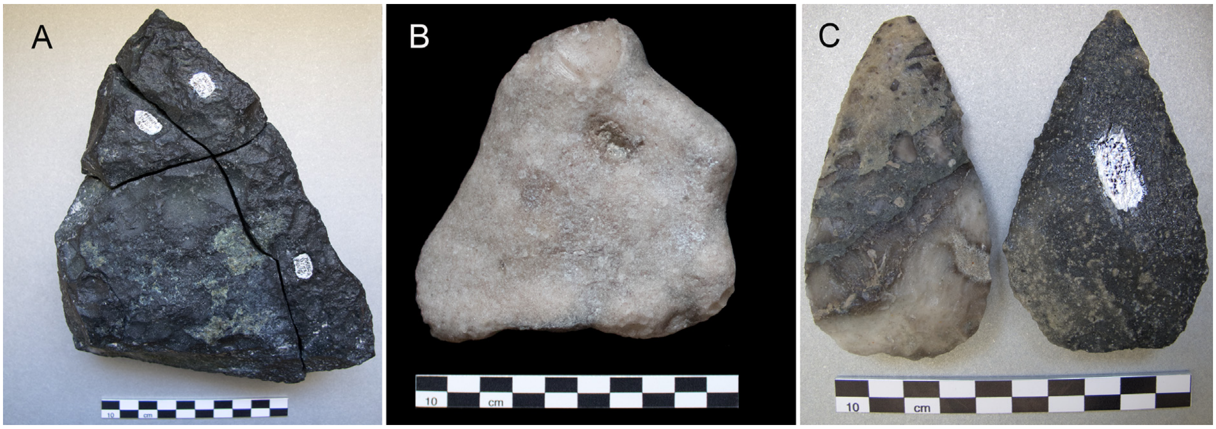


Fig. 4. Examples of silcrete raw materials and their condition from MSA sites in the Makgadikgadi Pans. A) Refitted silcrete block with window scar from checking of interior raw material quality (lower left corner), MAK14O. B) Natural silcrete blank with window scar, MAK33. C) Bifacial points in multi-hued and black silcrete, MAK15 and MAK14 area.

vary greatly within a single block (see Section 2.4). This complicates the separation of debris into original knapping groups, if these are based purely on visual characteristics. Without refitting, identifying separate blocks of raw material from the Makgadikgadi assemblages would have been virtually impossible. This contrasts with archaeological assemblages from northwest Botswana (Coulson et al., 2011; Nash et al., 2013b; Nash et al., 2016), where silcrete blocks and outcrops are more visibly distinct.

Kalahari silcrete has a conchoidal fracture pattern and is generally suited for both the production of tools with invasive retouch and extensive thinning, such as the bifacial points that are characteristic for the area. At the Makgadikgadi sites, we saw repeated evidence of initial test removals, or “windows”, to determine the interior quality of blocks (Fig. 4A and B). There was also ample evidence for internal faults causing unexpected fractures, shattering or Hertzian cone formations during knapping, especially at MAK33. This is probably caused by the abovementioned internal variations within each block and does not necessarily reflect the capabilities of the knappers. One as yet unexplained feature at MAK33 was the presence of a multitude of silcrete blocks of poorer knapping qualities. These blocks, weighing more than 70 kg total, tended to show only the scars from initial testing or were completely unworked. In the few cases where they had been knapped, they showed a distinct tendency to shatter. It is unclear whether these were brought to the site as lithic raw material or for some other, unknown and unrelated purpose, or were already on-site. In general, breakage other than that resulting from knapping, was fairly rare at all the excavated sites. This was somewhat surprising, given the abundant animal tracks crossing many of the sites, but presumably the soft clay surface has somewhat cushioned artefacts from breaking (also see Staurset et al., 2022 for details on disturbance from animal tracks).

In general, the excavated MSA lithic assemblages were found to be in fresh to mint condition; i.e. artefacts had minimal edge damage and retained sharp dorsal ridges (see Table 1). At sites MAK14K and MAK33 we observed slight differential weathering between buried and exposed artefacts. At MAK14K, a flake recovered from beneath an adjacent dune was less weathered than the excavated surface assemblage. Similarly, artefacts excavated from the subsurface layer at MAK33 retained pristine edges and original colour, whilst those from the surface were marginally less fresh. Occasionally, some of the distant outliers, which contrasted to the rest of the assemblage also in terms of technology and raw material, would display substantial weathering and patination. This indicates that local conditions for lithic preservation can vary greatly within relatively short distances in this pan environment. Artefact damage from burning (i.e., cracking, crazing, shrinkage, potlid formation, changes in colour and lustre; Purdy, 1975) was very rare. We saw no burnt point fragments, which could have indicated the cooking of meat (Coulson and Andreasen, 2020; Lombard, 2006; Skar and Coulson, 1990). Nor did we observe any traces of intentional heat alteration, commonly seen at South African MSA sites (e.g., Brown, et al., 2008; Brown et al., 2009; Schmidt et al., 2015; Schmidt, 2016; Schmidt and Mackay, 2016; Schmidt, 2017; Schmidt et al., 2017; Wadley and Prinsloo, 2014). This is unsurprising, given recent experimental evidence that Kalahari silcretes do not require thermal treatment, and that this practice deteriorates rather than improves its knapping quality (Nash et al., 2019; Schmidt et al., 2017).

3. The MSA lithic industry of the Makgadikgadi

There is currently no generally accepted typology covering the southern African MSA or the Kalahari region itself (Coulson et al., 2022). Unsurprisingly, the comprehensive local chronologies and lithic industries documented for example in South Africa (e.g., Lombard, et al., 2012; Wadley, 2015; Wurz, 2018; Wurz, 2019 and references therein) do not provide an adequate framework within which the Makgadikgadi assemblages can be analysed. The full point production strategies characteristic of the Makgadikgadi basin are not reflected in current MSA literature. Neither has this particular combination of technological approaches from within a prepared core framework hitherto been identified in the Kalahari. In describing the assemblages from Ntwetwe Pan we will attempt to document this proposed new industry using standard terminology such as “Levallois” or “discoid” whilst defining the Makgadikgadi artefact types based on the characteristics of the assemblages themselves.

This section outlines the characteristics observed for the Makgadikgadi MSA assemblages, beginning with main core reduction strategies and tool production goals, before continuing with the presence or absence of specific stages of the *chaîne opératoire* and outlining differences between the sites, and finally exploring some behavioural inferences from this investigation. As MAK33 has provided the most comprehensive archaeological dataset and subsequently was the focus of the refitting study, most of the results below originate from the analysis of this larger assemblage. However, the smaller excavations and the surveyed sites offer important nuance with which to balance the representativeness of the MAK33 results. These lesser localities also provide a landscape perspective, in anticipation that inclusion of a diversity of archaeological sites can illustrate aspects of hunter-gatherer behaviour that are seldom prioritized (also see Hallinan, 2021).

3.1. Core reduction strategies and blank acquisition

In contrast to previously excavated MSA sites in northwest Botswana, where discoidal core strategies were commonly used in blank production (Brooks and Yellen, 1977; Brooks et al., 2006; Coulson et al., 2011; Robbins et al., 2000b), Levallois approaches were predominantly pursued in the Makgadikgadi basin. This may reflect the relatively large size of available raw material blocks, where the thickness of the tabular pieces chosen for blank production often exceeded 20 cm. All the excavated assemblages contained Levallois products, either as cores, blanks or finished points (see Table 3). We were able to reconstruct several Levallois blank production sequences at MAK33. Several of these cores exhibited two sets of single preferential Levallois flake detachments, where usually the Levallois flake itself could not be located on site and had presumably been used for tool production and/or removed when the site was abandoned. One such example of a refitted sequence can be seen in Fig. 5 (see also Staurset et al., 2022). This indicates that the core was brought to MAK33 in a partially prepared state, worked there to produce a minimum of two Levallois flakes, and subsequently abandoned. This appears to be a common pattern at sites MAK33, MAK14O and MAK14K, where several stages of Levallois production are present. We also encountered several examples of recurrent Levallois production, often utilizing the generally elongated shape of the tabular blocks of silcrete to produce laminar preferential removals from a single platform. We found no examples of production of classic, unretouched Levallois points; the preferential flakes tended to be either oval to circular, or laminar. There does not appear to be a clear division between recurrent and single preferential Levallois core reduction sequences, and some indications that both could be used in sequence on a single, larger block of raw material. This could be a case of the technological approach being largely determined by the

Fig. 5. Examples cores from Makgadikgadi MSA sites, all in silcrete. A) Exhausted Levallois core, MAK14K. B) Levallois core, MAK33. C) Refitted Kombewa core and Janus flake with siret break, MAK14O. D) Refitted recurrent Levallois core, MAK33.

size and shape of the block, and not a stringent, predetermined set of rules.

The impression that blank production was largely determined by the shape of the original block of material was reinforced by the presence of other prepared core strategies; Kombewa and discoidal. Kombewa reduction is a widespread but rarely reported phenomenon in the MSA and Middle Palaeolithic (Bourguignon and Turq, 2003; Casini, 2010; Coulson et al., 2011; Dibble et al., 2012; Jones, 2016; McBrearty, 1988; Niang and Ndiaye, 2016; Shea, 2008; Spinapolice and Garcea, 2014; Tixier and Turq, 2011; Villa et al., 2010), first recognized in Kenya (Owen, 1938). It involves using the butt of a large flake as the point of detachment for producing an inverse, symmetrical removal that appears to have two ventral surfaces: a Janus flake. Unsurprisingly, this procedure often results in a misstrike, as can be seen in the refitted *siret* break illustrated in Fig. 5. This hard hammer knapping error produces a detachment that splits along the percussion axis into two equally-sized pieces (see Inizan et al., 1999). We found Kombewa cores and/or Janus flakes at the three larger excavations and at several surveyed sites, but never as a dominant blank production strategy. Discoidal cores and products were also a lesser but never main element in the assemblages. These cores were generally smaller than other prepared core examples, and usually exhaustively worked. However, we do not currently have enough examples of these last two approaches to recognize subtypes of discoid or Kombewa production. The stages of the three prepared core reduction strategies and their corresponding debris are summarized in schematic form in Table 2. As expected, in addition to these recognized strategies, a small number of amorphous cores were recovered from most sites. Refitted amorphous cores from MAK33 indicate that the probable motivation for the removal sequence was chiefly to reduce a block of raw material in search of sections that were more fine-grained and less brittle (Staurset et al., 2022).

Reduction approach notwithstanding, the preferred blank appeared to be a flat, elongated flake of moderate thickness and a gently tapering edge, which was large enough to be significantly modified by retouch. Importantly, in the Makgadikgadi these were not just acquired by core reduction. At all excavated sites we also found natural blanks, or points produced from them. These artefacts were of similar size and shape as the flake blanks, but tended to be thicker, and both sides carried the heavily weathered surface commonly encountered on natural pieces of pan silcrete (see Fig. 6). This outer surface tended to be partially preserved also on the finished tools. The natural blanks and products from these were limited to a small number of raw material groups, mostly comprising very fine-grained, well cemented silcrete in light to white colours (also see Nash et al., 2022). This is likely the result of these particular types of silcrete forming in thin enough layers that they form natural blanks, and could be exploited directly by bifacial reduction for point production. It is important to note that this reduction approach, by definition, categorises the resulting points as core tools rather than flake tools. This may however be a

Table 2
Schematic visualization of the prepared core production of blanks and the characteristic debris remaining at MSA Makgadikgadi sites.

Core stage	Reduction approach		
	Levallois	Discoid	Kombewa
1) Raw material selection	• Tested/untested blocks of raw material • "Window" flakes		• Large blocks
2) Decortication/ Core shaping	• Fully/partially corticated core shaping flakes		N/A
3) Platform preparation	• Small flakes • Larger removals from preparing preferential striking platform	• Small flakes	• Small flakes
4) Blank production	• Negative space within refitted block corresponding to Levallois flake • Rejected Levallois flakes	• Negative space within refitted block corresponding to discoidal blank • Rejected *déjeté* flakes	• Negative space within refitted block corresponding to Janus flake • Rejected Janus flakes
	- Repeat stages 2-4 as needed -		
5) Core abandonment	• Exhausted Levallois cores	• Exhausted discoidal cores	• Exhausted Kombewa cores (i.e., large flakes with sizable removal scar on the ventral face)

Table 3
Overview of notable artefact types at the excavated Makgadikgadi MSA sites. Includes complete/virtually complete tools and cores (not fragments), and finished/virtually finished tools (not roughouts).

Site (total)	Cores				Points			Other tool categories		
	Levallois cores	Discoidal cores	Kombewa cores	Other cores	Unifacial points	Bifacial points	Levallois points	Elongated scrapers	Other scrapers	Misc. Retouched pieces
MAK2						4			1	
MAK14K	4	1			2	3			1	3
MAK14O	4		1	1	10	12			3	4
MAK15	1			1	1					1
MAK33	7	3		14	22	37	4	10		10

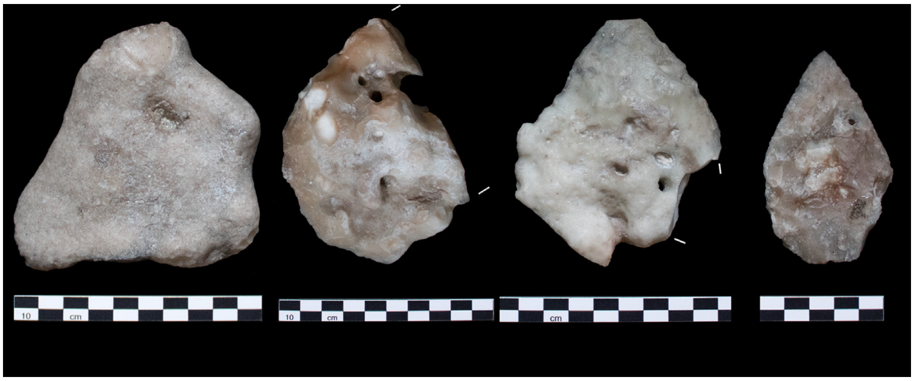


Fig. 6. Stages of MSA point production from natural blank to bifacial point. White lines on central artefacts indicate breaks. All in silcrete from site MAK33.

distinction that has more importance to lithic analysts than prehistoric peoples, as the resulting tool shapes are virtually identical. The use of natural blanks for MSA point production in the Makgadikgadi basin could be argued to parallel instances of Acheulean use of large flakes for the production of the core tool *par excellence*, handaxes (e.g., Sharon, 2010; Sharon, 2011; Texier and Roche, 1995).

3.2. Making points: tool production goals

Whilst there were numerous ways of acquiring "ideal" blanks at the excavated MSA sites, the later stages of tool production differ markedly in that these appear to have been following a stringent set of rules. At all sites, excavated or surveyed, the MSA tool category was dominated by well executed, highly retouched points (see examples in Fig. 7). By point we refer here to the typological category comprising convergent, intentionally produced, symmetrical tools suitable for hafting, with no inference as to their intended function.

The stages of point production can be summarized as follows (see Fig. 8). The blanks (produced or natural) are shaped by medium to large, shallow, invasive shaping removals, which can be completed using either bifacial or unifacial approaches. The original blank surface is normally completely removed by the invasive retouch. Some original surface will occasionally remain, especially on the flatter ventral face of bifacial points. During the shaping phase, the proximal ends are carefully thinned, bulbar and butt areas removed and converted into a symmetrical, rounded base. Interestingly, this shaping and thinning phase was often achieved using soft hammer, as evidenced by the presence of lipped shaping removals at MAK33 (following Inizan et al., 1999:213). The amount of preparation and detail around the base indicates the points were likely intended to be hafted. The lateral edges are straightened,

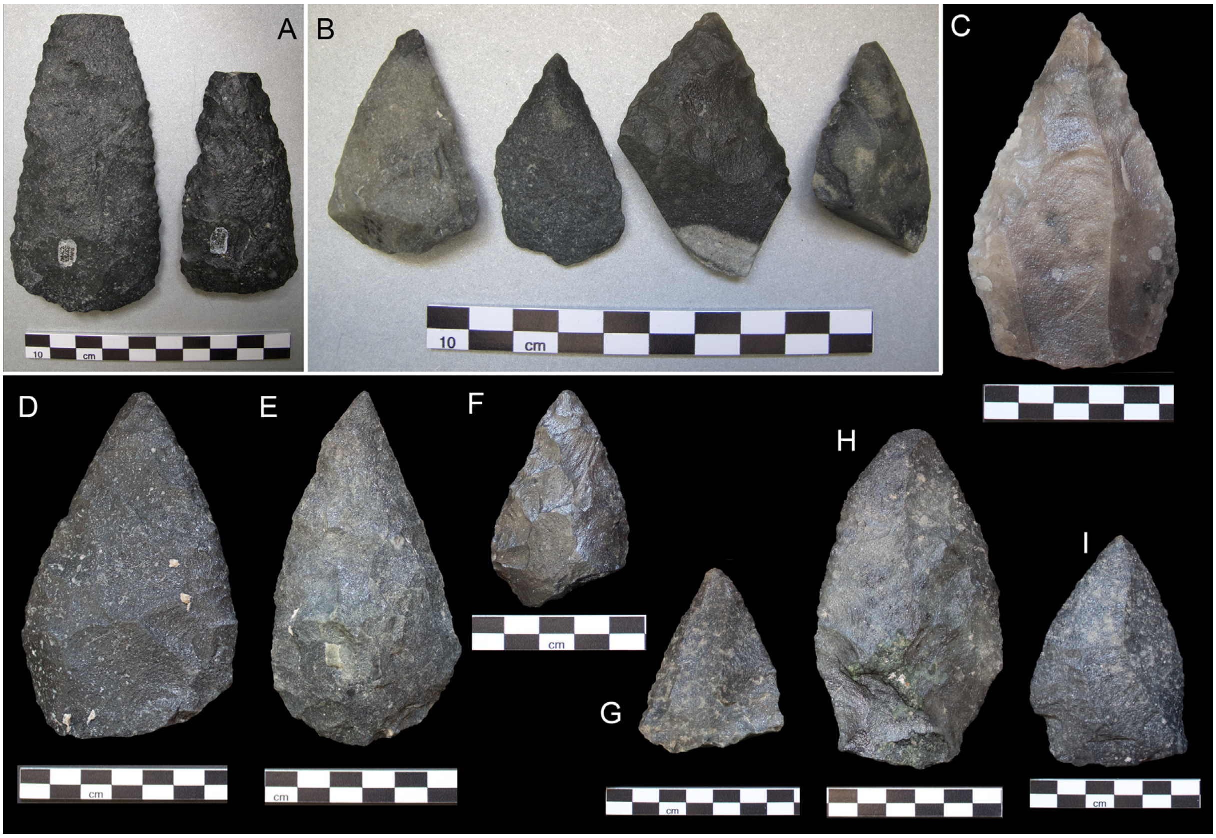
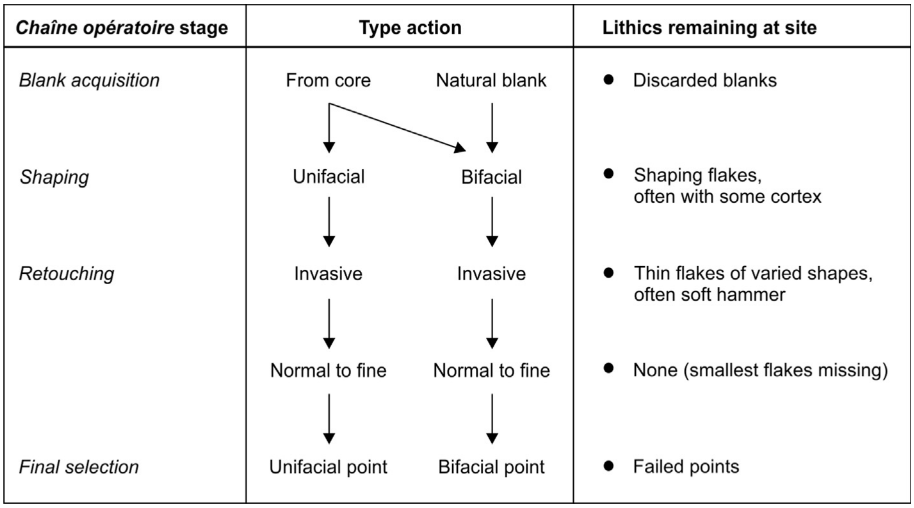


Fig. 7. MSA points from excavated Makgadikgadi sites, all in silcrete. A) Bifacial points, MAK2. B) Bifacial points from MAK14O. C) Partial bifacial point, MAK33. D-F) Bifacial points, MAK33. G-H) Unifacial points, MAK33. I) Levallois point with retouch, MAK33.



***Chaîne opératoire* stage**	**Type action**		**Lithics remaining at site**
Blank acquisition	From core	Natural blank	• Discarded blanks
Shaping	Unifacial	Bifacial	• Shaping flakes, often with some cortex
Retouching	Invasive	Invasive	• Thin flakes of varied shapes, often soft hammer
	Normal to fine	Normal to fine	• None (smallest flakes missing)
Final selection	Unifacial point	Bifacial point	• Failed points

Fig. 8. Schematic visualization of point production stages and the debris remaining at MSA Makgadikgadi sites.

while the distal end is transformed into a sharp tip by several rows of retouch. Finally, shallower rows of normal to fine finishing retouch are applied to remove remaining irregularities and complete the tool. During these final stages, many points were abandoned in manufacture due to (seemingly minor) breaks around the tip or (unintentionally) deep removals along the lateral edges. These imperfect, discarded examples provide important information about the production process, its goals and selection criteria. For example, they illustrate that the amount of both invasive and normal retouch applied to a tool varied according to the grain size of the raw materials. Fine-grained silcrete can retain elaborate retouch and was used to fashion more gracile points. Points in more coarse-grained silcrete generally conformed to the same morphometric shape but were usually thicker and displayed less intricate retouch.

Across the investigated area, bifacial points dominated unifacial types. Both were however produced in the same manner, and the choice of one type over the other may have been determined by the shape of the blank. Unifacial points completely lacked invasive removals on the ventral face but could display minor applications of inverse retouch to regularize the edges. The result was that both types of points shared the same general morphological shape. A more striking feature distinguishing the points was size – points vary in length between 25 and 118 mm. The variable size did not correlate with using either unifacial or bifacial reduction, but could potentially be related to intended purpose, including use as hand-held tools or projectiles with various modes of propulsion. While detailed size and morphological analysis of the points has not been undertaken, the overall size of the Makgadikgadi points argues against widespread use of complex projectile technology such as bow and arrow or spear throwers/atlatls (see also Brooks et al., 2006). Regardless of size, it appears that ensuring points were symmetrical and not too thick was a key priority. The large number of (to modern eyes) near-perfect, undamaged points that had been abandoned, both at the excavated sites and across the pan, indicates a high level of knapping skill and knowledge of the raw material, as well as stringent templates for the finished tools.

Besides points, retouched MSA tools were rare across the pan. Amongst these, only one type had a higher representation than most: scrapers (see Fig. 9). One distinctive scraper type was recovered from MAK33 and observed at several surveyed sites. This was produced on large, elongated blanks by the application of direct normal retouch where needed to regularize one or both of the edges. Where preserved, the distal end was usually retouched into a convergent shape, but not to a symmetrical tip. Importantly, the proximal end of the hard hammer blanks had not been thinned and remained significantly thicker than the rest of the tool. This likely indicates that these elongated scrapers, in opposition to the points, were intended for hand-held use. Besides these, there were too few other scrapers (see Table 3) from excavated contexts to establish a typology. Both end and side scrapers were present, and the few we recovered did not appear to adhere to stringent morphology or production criteria. In this regard these tools differed markedly from the points, as the scraper types appeared more impromptu than the rigorous procedure that characterized point manufacture. Besides these two categories, and a small number of miscellaneous retouched pieces, one final tool type was identified: a steep double-sided scraper (see Fig. 9). These distinct artefacts were only documented at surveyed sites, particularly in the MAK14 area. They were made on thick (>1.5 cm) flakes and formed by steep scalar retouch, which reduced the tool until its cross-section was virtually square. Hopefully, future investigations will shed more light on the spread, use and technological context of these tools. Notably, several common MSA tool categories were not recovered, such as denticulates, awls and burins (or their spalls). Neither were these tools present at surveyed Ntwetwe sites, indicating their general absence within this industry.

3.3. Differences in tool production between excavated sites

As outlined above, the main tool production goal at both excavated and surveyed MSA sites was highly retouched points. The basic approach to how these were made also appeared remarkably similar across the surveyed area. There were however some local nuances, of which the most striking is the difference in point size (see Table 4). The datasets from MAK2 and MAK15 are perhaps too small to draw firm conclusions. However, the points from MAK14K and MAK14O are significantly smaller than those from MAK33. This could be the result of several factors, including changing traditions over time (as the sites are dated to at least two separate dry periods between lake high-stands; for a full discussion of the chronology see Burrough et al., 2022) and/or differences in raw material block

Fig. 9. Non-point tools from the Makgadikgadi MSA sites. A) Distinct, elongated scrapers from MAK33. B) Steep double-sided scraper with scalar retouch from the MAK14 area.

Table 4
Average length, width and thickness of points from the excavated Makgadikgadi sites. Numbers of points measured can be found in Table 3. All measurements in cm.

Site	Min-max length (average)	Min-max width (average)	Min-max thickness (average)
MAK2	5–10.8 (7.7)	2.9–5.5 (4.3)	0.9–1.2 (1)
MAK14K	3.8–5.0 (4.2)	2.5–4 (3.3)	0.6–1.2 (0.9)
MAK14O	2.5–6 (4.4)	2–4.8 (2.9)	0.4–1.6 (1)
MAK15	2.5–6.2 (4.4)	2–4.6 (3.3)	0.6–1.4 (1)
MAK33	4.3–11.9 (7.5)	3.5–6.6 (5)	0.6–2.4 (1.3)

selection. It could also imply the tools served different functions, or if used as spearheads, different methods of propulsion (see also Brooks et al., 2006). There were two additional notable differences in the tool production: choice of prepared core technology and variations in production technique. With regard to these differences, we consider the data sample from MAK2 and MAK15 too small to form part of this discussion, and focus on sites MAK14K, MAK14O and MAK33. Given the size of the blanks needed to make the points, it is unsurprising that Levallois approaches to blank production dominate the assemblages at these three larger sites (see Table 3). However, the relative proportion of discoidal and Kombewa production vary somewhat. This could simply be caused by different sizes and shapes of selected raw material blocks, or it could imply variations in toolmaking traditions. Similarly, we observed some minor variation in tool shaping and retouching technique. For example, at MAK33 soft hammer is often used for point shaping and invasive reduction. This was not observed at other sites. There were also small differences in the extent to which the platforms and core faces were prepared prior to detachment. This will be further explored in a future publication. Importantly, in addition to these variations in tool production, different stages of the *chaîne opératoire* could be observed at the excavated sites. These also warrant further investigation.

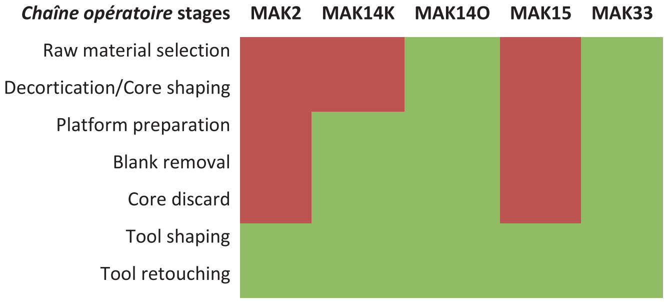
3.4. Presence and absence of chaîne opératoire stages

One defining aspect of the *chaîne opératoire* is its potential for mapping out the life cycle of artefacts through technological stages and the human actions leading to each. This dynamic view of human-artefact interaction opens additional possibilities at sites that are fully excavated and have no indication of repeat use (Staurset et al., 2022). One such possibility is assessing not just which stages of the *chaîne opératoire* - and their corresponding human actions - are present, but which are absent, and hence presumably occurred off-site. This allows for a fuller behavioural reconstruction, which can include some activities that affected the materials prior to them arriving on site and, tentatively, activities occurring after export from the site. As described above, technological stages from raw material selection through blank production and tool manufacture for a range of core strategies are present at the excavated sites. When these stages are applied to the separate sites and raw material groups, an increasingly complex image emerges.

In mapping out which technological stages are present at each excavated site, the smaller MAK2 and MAK15 cluster at one end of the scale (see Table 5). Dominated by the final stages of point production and subsequent rejection of tools deemed unsuitable, neither of these sites have evidence of initial stage production. This implies that lithics arrived on these sites as partially prepared points or, to a lesser extent, as blanks. Site MAK14K has similar evidence of finalizing tools, but in addition there is evidence for blank production. Both blanks and partially prepared cores appear to have been introduced to this site. On the opposite end of the scale are sites MAK14O and MAK33, where the much fuller assemblages comprise evidence ranging from initial raw material block selection through all production stages to the finished tool. In addition to prepared cores, blanks and tools, raw material blocks with no modification or only initial testing have been imported to these sites. This could indicate that MAK14O and MAK33 has witnessed comprehensive tool production, while debris-producing activities at MAK2/MAK15 largely comprised ad-hoc retooling. Following distance-decay models (e.g., Ambrose, 2012; Andrefsky, 2009; Barton and Riel-Salvatore, 2014; Barut, 1994; Binford, 1980; Brantingham, 2006; Merrick et al., 1994; Minichillo, 2006; Pleurdeau et al., 2014) this could also be used to argue that MAK14O and MAK33 (and to a lesser degree, MAK14K) are likely closer to the main raw material sources, while the two latter would be located further from the outcrops. However, MAK15, MAK2, MAK14K and MAK14O are located within 3.5 km of each other (see Fig. 1); MAK14K and MAK14O are separated only by 150 m. Further, using geochemical and petrographic evidence, Nash et al. (2022) show that distances to silcrete sources for these sites do not conform to base assumptions for distance-decay models. The difference in which production stages are present at the various sites therefore requires additional explanatory factors than distance (e.g., accessibility, variations in preference of certain raw material sources or mobility factors entirely unrelated to lithic raw material acquisition). Importantly, given that a single knapper can produce a sizeable amount of debris in minutes (e.g., Boëda and Pelegrin, 1985; Bowers et al., 1983; Hiscock, 2002; Newcomer and Sieveking, 1980; Pelegrin, 1991; Putt, 2015; Schick, 1987; Stahle and Dunn, 1982), the larger assemblages at MAK14O and MAK33 should not be taken as indications that these sites necessarily were in use over a longer time period or by more people than the smaller sites. It bears repeating that the assemblages only reflect human activities associated with lithic material, likely comprising only a fraction of the actual prehistoric pursuits undertaken at each site.

MAK33, which yielded the most comprehensive knapping sequences, warrants further discussion in this regard. Based on the extensive refitting (Staurset et al., 2022), artefacts were imported to this site as blocks of raw material, partially prepared cores, partially finished tools and, in a few rare cases, as blanks. Exported artefacts included partially worked cores, blanks, and finished tools. What remained on site was unworked blocks of raw material (some of which may already have been present), debris from core cleaning, debris from tool shaping and retouching, discarded blanks,

Table 5
Summary of main chaîne opératoire stages at the MSA excavated sites, where green indicates presence and red absence. By raw material selection we here mean the presence of unworked lithic raw material suitable for tool production.



Chaîne opératoire stages	MAK2	MAK14K	MAK14O	MAK15	MAK33
Raw material selection	🟥	🟥	🟩	🟥	🟩
Decortication/Core shaping	🟥	🟥	🟩	🟥	🟩
Platform preparation	🟥	🟩	🟩	🟥	🟩
Blank removal	🟥	🟩	🟩	🟥	🟩
Core discard	🟥	🟩	🟩	🟥	🟩
Tool shaping	🟩	🟩	🟩	🟩	🟩
Tool retouching	🟩	🟩	🟩	🟩	🟩

discarded tools at various stages of manufacture, and exhausted cores. The activities thus appear to reflect net export of tools and materials for tool manufacture for use elsewhere, rather than local retooling for immediate use. This emphasizes the need to view transport of lithics as an integrated part of tool production in this environment, where a single core and its products were worked at multiple locations (see also Nash et al., 2013b; Nash et al., 2016). However, if the *chaîne opératoire* stage classifications are applied across the different raw material groups at MAK33, more differential production patterns appear (see Table 6). The complete sequence of stages was not present for all raw material groups, as illustrated by the three following examples. Group A is large group of light to medium grey silcrete consisting of several blocks (see SOM1 in Staurset et al., 2022). This group comprised technological stages ranging from the import of partially prepared Levallois cores, through blank and tool production, to discard of exhausted cores and tools abandoned in manufacture (this group also includes the refitted core in Fig. 5D). This contrasts to the much smaller group I, a distinctive light-coloured, fine-grained silcrete with occasional glassy areas. No evidence of early-stage production was recovered in this raw material. There were however several examples of late stage shaping and retouching of bifacial points. This raw material appears to have been brought to the site exclusively as partially finished tools (see Fig. 7C). Finally, group K provides a third perspective. A fine-grained, almost white silcrete, this was solely used to produce bifacial points from natural blanks (see examples in Fig. 6). On-site *chaîne opératoire* stages ranged from unmodified raw material pieces to finished points, excluding the core and blank production stages that do not apply when producing core tools. In short, which stages of the *chaîne opératoire* were present did not just differ between the excavated sites, but between different raw material groups within a single site. This implies an unexpectedly complex pattern of lithic transport, likely involving multiple silcrete outcrops and movement between several archaeological sites.

Given both the longer production sequences of raw material groups such as A at MAK33, and the number of reduction sequences involved, it would be easy to hypothesize that this raw material originated from an outcrop in the immediate vicinity of the site. The numerous natural blanks of group K would also be a likely candidate for local raw material acquisition, although these are smaller and would be easier to transport than the larger blocks in group A. Geochemical provenancing of waste manufacturing flakes representative of groups A and K, however, indicate that group A likely originated 25 km southeast of MAK33, and group K 24 km to the northeast (Nash et al., 2022). This implies that i) carrying both large and smaller blocks suitable for tool production over moderate distances was a standard behaviour, and ii) MAK33 was preferred as a place for tool production over the outcrop sites. These results also underline the importance of geochemical provenancing when addressing how raw material access and transport affected patterns of mobility and landscape use in the Makgadikgadi during the MSA. A useful contrast to A and K is provided by raw material group I, which has not yet been provenanced. This group exclusively exhibits late-stage production, and would therefore be a likely candidate for long-distance transport. Interestingly, at MAK14K and MAK14O, a similar fine-grained silcrete was reserved for late-stage production of bifacial points. This implies that the suitability of silcrete of this type for this particular purpose was understood in this landscape and/or time period.

Finally, one stage of the *chaîne opératoire* yet to be addressed here is damage from use and subsequent reshaping or retooling. While we located MSA points with impact fractures during the Ntwetwe survey (following definitions described by Bergman and Newcomer, 1983; Fischer et al., 1984; Villa and Lenoir, 2009), there was no clear indication of these at the excavated sites. Several points from MAK33 displayed breaks near the base, but experiments with similar points in silcrete are required to conclude whether this happened during impact. Neither of the excavated assemblages evidence resharpening, curation or recycling of tools (Inizan et al., 1999:96). This reinforces the impression that activities at least at the larger excavated sites are concentrated in the earlier stages of the *chaîne opératoire*. It also indicates that the knappers had ready access to silcrete outcrops, were selective and had determined a set of criteria even before collecting the raw material.

4. The Makgadikgadi Middle Stone Age in a chrono-cultural context

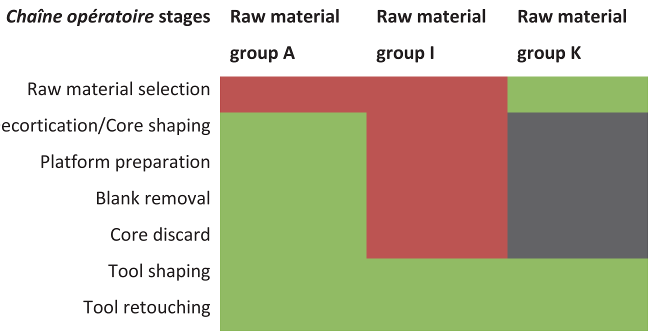
The combined surveys and excavated sites described above make it possible to attempt to place the Makgadikgadi toolmaking tradition within a wider chrono-cultural context.

4.1. Other Kalahari MSA sites

While we fully acknowledge differences in the depth of deposits and the stratigraphic nature of the archaeological sequences compared to other Kalahari sites, both technological approach and tool choice in the Makgadikgadi MSA share important aspects with three excavated sites from northwest Botswana. Of particular interest are White Paintings Shelter and Rhino Cave in the Tsodilo Hills, and ≠Gi Pan near the Aha Hills. The semi-open *White Paintings Shelter* is located at the base of Male Hill. During

Table 6

Summary of main chaîne opératoire stages of three different raw material groups from site MAK33, where green indicates presence, red absence and black that this stage does not feature in the relevant reduction strategy (points made on natural blanks). By raw material selection we here mean the presence of unworked lithic raw material suitable for tool production.



***Chaîne opératoire* stages**	**Raw material group A**	**Raw material group I**	**Raw material group K**
Raw material selection	🟥	🟥	🟩
Decortication/Core shaping	🟩	🟥	⬛
Platform preparation	🟩	🟥	⬛
Blank removal	🟩	🟥	⬛
Core discard	🟩	🟥	⬛
Tool shaping	🟩	🟩	🟩
Tool retouching	🟩	🟩	🟩

Fig. 10. Examples of MSA points from sites in Northern Botswana. A) White Paintings Shelter, Tsodilo Hills. B) Rhino Cave, Tsodilo Hills. C) Corner Cave, Tsodilo Hills. D) ≠Gi Pan, near the Aha Hills. E) Kudiakam Pan, northern Makgadikgadi Basin. F) Samedupe Drift, Boteti River. Photos: Sigrid Staurset.

1989–1993, 31 m^2 was excavated here, some to a total depth of 7 m (Feathers, 1997; Kokis et al., 1998; Robbins et al., 2000b; Robbins, 1990; Robbins, 1999; Robbins et al., 2012; Robbins et al., 2016; Stewart et al., 1991). The integrity of the sedimentary stratigraphy associated with the shelter's 90 kyr time range (Ivester et al., 2010), has, more recently, been reassessed based on post-depositional disturbance identified through refitting (Staurset and Coulson, 2014). The more enclosed *Rhino Cave* is a narrow hillside fissure on Female Hill with a large panel of cupules. A total of 5.25 m^2 was excavated here to a maximum depth of 185 cm during 1995–2006 (Coulson et al., 2011; Ivester et al., 2010; Robbins et al., 2000a; Robbins et al., 1996). The large MSA assemblage from this small site has been interpreted to reflect both occupation and flint knapping (Robbins et al., 2000a), and ritualized behaviours (Coulson et al., 2011). During 1969–1982 large trench excavations were undertaken at *≠Gi Pan*, located near the Aha Hills. The large and heavily curated MSA assemblage included almost 600 points, a number of which had impact fractures. These were found in association with abundant faunal remains from various prey species (Brooks and Yellen, 1977; Helgren and Brooks, 1983). The site was therefore interpreted as a specialized large-game hunting location, where complex projectile technology such as spear throwers were likely used (Brooks et al., 2006). Recent geochemical provenancing of artefacts from these three sites, as well as from the unpublished site Corner Cave (also at Tsodilo Hills), show that silcrete was repeatedly imported from source areas at least 295 km away (Nash et al., 2013b; Nash et al., 2016), despite the presence of local quartz and quartzite at Tsodilo and chert in the Aha Hills. Given the abundance of silcrete at Ntwetwe pan and its MSA sites, this surprisingly high-mobility pattern of tool production in northwest Botswana is of particular interest and warrants further investigation. Despite the challenges of dating, the emergent picture of the regional Kalahari MSA currently places it broadly between 94 ± 9 ka and 52 ± 7 ka consistent with sites in the Makgadikgadi such as MAK14K (which can be constrained geochronologically to between 81 ± 6 and 72 ± 5; for a full discussion see Burrough et al., 2022).

Assemblages from White Paintings Shelter, Rhino Cave and ≠Gi comprise prepared core technology for blank production. Points constitute the most common tool category, and most of these are highly retouched (see Fig. 10). There are however also significant differences between the north-western Botswana sites and those in the Makgadikgadi, both concerning lithic production and on-site behaviour. One major difference lies in raw material choice (see Section 2.5). While the Makgadikgadi MSA assemblages are exclusively silcrete, the three others also include quartzite and chert, in addition to quartz at the two Tsodilo Hills sites (Brooks et al., 2006; Coulson et al., 2011; Helgren and Brooks, 1983; Nash et al., 2016; Robbins et al., 2000b). With regard to blank production, both discoidal and Levallois strategies are prevalent at the two Tsodilo Hills sites (Coulson et al., 2011; Robbins et al., 2000b), while the ≠Gi assemblage reportedly has chiefly discoidal reduction[2] (Brooks and Yellen, 1977; Brooks et al., 2006). This contrasts with the Levallois-dominated production found in the Makgadikgadi basin, as does the complete lack of points made from natural blanks at the north-western MSA sites. Neither is the laminar technology component of some Makgadikgadi sites present at the north-western sites (Brooks and Yellen, 1977; Brooks et al., 2006; Coulson et al., 2011; Staurset and Coulson, 2014). More strikingly, the Makgadikgadi points tend to be much larger in size than those from the earlier excavated sites. This tendency could relate to the larger size of easily accessible silcrete blocks in the Makgadikgadi basin, in contrast to the habitual long-distance raw material transport identified in the northwest. Note also that there is greater morphological variety within point shapes at the three north-western Botswana MSA sites compared to the relatively uniform Makgadikgadi MSA. This could be due to the former sites being repeatedly occupied through periods of the MSA, while there are no indications of repeat visits to the latter (Staurset et al., 2022).

Interestingly, there is a larger number of other formal tools relative to points at the north-western Botswana sites – particularly scrapers – where all assemblages also include denticulates and burins (or burin spalls), and one or more include awls, notched pieces, becs and *outils écaillées*[3] (Brooks and Yellen, 1977; Brooks

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[2] Levallois reduction has not previously been reported at ≠Gi. Several cores have however recently been observed in the assemblage, as has a small number of Kombewa examples (by contributor SS). Kombewa reduction is also reported at Rhino Cave (Coulson et al., 2011).

[3] A flake or blade with one or usually both facets of the working edge battered and splintered from use (see White, 1968; for detailed description).

et al., 2006; Coulson et al., 2011; Robbins et al., 2000b). The higher number of tool categories in the northwest Botswana MSA could reflect variations in site use, cultural traditions or, perhaps most likely, some combination thereof. With regard to site use an interesting contrast is provided by ≠Gi, the only other excavated open-air site. The characteristic, highly retouched points from ≠Gi frequently had indicators of use, including impact fractures, resharpening, and recycling of points into scrapers (Brooks et al., 2006; Helgren and Brooks, 1983). As mentioned above, these attributes in combination with its pan edge location and large faunal assemblage have led to its interpretation as a repeatedly used, specialized hunting site. That the excavated Makgadikgadi sites lack any of these characteristics, could indicate their primary function was not hunting.

As discussed in Coulson et al. (2022), several MSA surface collections and salvage excavations have taken place in and around the Makgadikgadi basin, particularly at the numerous smaller pans. Examples from three of these sites, Kudiakam Pan, Ngxaishini Pan and Samedupe Drift, illustrate how elements of the Makgadikgadi MSA industry are present within the basin (see Fig. 10). The MSA site of *Kudiakam*, a large seasonal pan within the Makgadikgadi basin just south of Nxai Pan National Park, was published by Robbins (1987, 1989). Surface collections yielded Levallois and discoidal cores and several retouched tools, including MSA points, scrapers and handaxes. *Ngxaishini Pan*, near Gweta, was recorded in 1993 by Robbins and Campbell (Robbins and Murphy, 1998). This site included lithics from the ESA, MSA and LSA, as well as faunal remains and hunting blinds. Many of the finds were embedded in a cement-like matrix. Stone tools were first reported at *Samedupe* (sometimes referred to as Samadupi or Samedupi) on the Boteti River by Wayland (1950). A large number of MSA lithics were surface collected close to silcrete outcrops at Samedupe Drift by Denbow (this unpublished collection is currently housed at the National Museum of Botswana). These included discoid and Levallois cores, numerous prepared flakes, elongated scrapers and MSA points (pers. obs., contributor SS).

4.2. Regional considerations

Given the limited chronological data from the Kalahari MSA, a connection to the South African MSA, undoubtedly the best documented in the region, would have provided interesting venues for discussing the spread of prehistoric humans and their technology. Unfortunately, there are few similarities in lithic production between these regions. The prevalence in South Africa of large, parallel-sided or convergent flakes in the MSA I and MSA II (for overviews see Mitchell, 2002; Sampson, 1972; Sampson, 1974; Wurz, 2019), find little resonance in the heavily retouched industries in the Middle Kalahari. The Still Bay (e.g., Lombard, et al., 2010; Rigaud et al., 2006; Vanhaeren et al., 2013; Villa et al., 2009) and Howiesons Poort (e.g., Porraz, et al., 2013; Thackeray and Kelly, 1988; Wurz, 2005) industries share an affinity for fine-grained materials, and in the case of the Still Bay, include invasively retouched bifacial points. Both blank production and point morphology however diverge from that seen in the Ntwetwe Pan.

The similarity of the north-western Kalahari MSA sites to the Bambata industry of Zimbabwe has been noted previously by several researchers (Brooks et al., 2006; Coulson et al., 2011; Helgren and Brooks, 1983; but compare Robbins and Murphy, 1998). Unfortunately, most Bambata sites were originally investigated under early archaeological research regimes (e.g., Armstrong, 1931; Cooke, 1950; Cooke, 1955; Cooke, 1963; Cooke, 1971; Hole, 1959; Jones, 1940; Jones and Summers, 1946; Summers, 1955), and consequently lack coherent chronologies (Haynes and Klimowicz, 2009; Larsson, 1996; Walker and Thorp, 1997). However, when reviewing tool and core types from, for example, the Lower and Middle MSA layers at Bambata Cave, the similarities to the Kalahari MSA are striking. Armstrong (1931) uncovered a varied assemblage with imported, fine-grained raw materials, highly retouched points, and Levallois and discoid lithic technologies. Similar arguments can be made for the lower levels of Zombepata Cave (Cooke, 1971; Larsson, 2007), and even for the Magosian levels at Khami (Jones and Summers, 1946). More recent work at Hwange National Park, Zimbabwe, shows that Bambata MSA can also be located in a Kalahari-adjacent environment (Haynes and Klimowicz, 2009; Klimowicz and Haynes, 1996). Nevertheless, while similarities regarding point shape and prepared core blank manufacture are evident at the Zimbabwean sites, they comprise more tool types and do not mirror the point-centric production characteristic of the Makgadikgadi MSA.

In Zambia, the large bifacial lanceolates of the Lupemban (Taylor, 2016 and references therein) form another potential comparative base. However, the Lupemban points are accompanied by core axes and backed blades – both elements that have no parallel in the Makgadikgadi MSA. Lupemban assemblages from Twin Rivers Kopje and Mumbwa Caves have been suggested to be similar to the Zimbabwean Bambata (Barham, 2000; Clark and Brown, 2001). Broadly similar bifacial points can be seen illustrated in publications from these sites and both Levallois and discoidal reduction are present, but their respective assemblages again comprise a wide range of tools not found at the Makgadikgadi sites. Another notable difference is the raw material: Mumbwa Caves is dominated by vein quartz and Twin Rivers Kopje by quartzites (Barham, 2000; Clark and Brown, 2001). Given the fracture patterns of these raw materials, prehistoric knappers would likely attain different results using these compared to Kalahari silcrete, lithic tradition notwithstanding. The shared typological and technological affinities with MSA sites towards the north and east (and the lack of such to the south) provide an interesting background for further investigations of regional migrations between contrasting environmental regions (see also Thomas et al., 2022).

5. Discussion and concluding remarks

The evidence presented in this paper results from recent archaeological surveys and full excavations of five open-air MSA sites in Ntwetwe Pan, Makgadikgadi Basin, Botswana. The consequent body of data illustrates the successful occupation of the subcontinent interior and forms a substantial contribution to our knowledge of a previously under-explored area of southern Africa. The challenges and opportunities presented by this landscape were addressed by a focus on technology as the initial point of analysis of an undocumented industry with clear connections to the MSA of north-western Botswana. The combination of full excavation of exposed surface assemblages and the application of a *chaîne opératoire* approach with an emphasis on refitting opened new possibilities for comparisons and behavioural reconstruction. Through the application of the *chaîne opératoire*, it is possible to surpass typological description by identifying the sequence of conscious choices made by the original artefact makers. The combined results of these individual sequences provide insight into behaviour patterns indicative of broader culturally determined traits and norms and open the possibility for reconstructing elusive “moments in time” (Wadley, 2012).

The excavated sites contain a previously undocumented MSA industry characterized by a limited toolkit (also see Coulson et al., 2022; Staurset et al., 2022; Thomas et al., 2022). This includes the use of Levallois, discoidal and Kombewa approaches to the production of blanks, which are subsequently shaped by invasive retouch on one or both faces into symmetrical points. These highly retouched points dominate tool production, which also include occasional side and end scrapers. Combined, the assemblages from the excavated sites illustrate a range of technological stages from raw material selection through blank production and tool manufacture. When these stages are applied to the separate sites and raw material groups, an increasingly complex image emerges. The smaller excavated sites, MAK2 and MAK15, display late-stage production and disjointed technological sequences. The medium-sized sites, MAK14K and MAK14O, also comprise core reduction. The largest site, MAK33, evidences the full *chaîne opératoire* from raw material block to discarded tool. Despite the open and exposed nature of the site, refitting results from MAK33 reveal surprisingly complete lithic production sequences. The internally consistent morphological and technological aspects of the lithic assemblages and their constituent raw materials at these sites indicate that they represent single periods of utilization (see further discussion in Staurset et al., 2022). Given the high mobility evidenced by earlier research in the Kalahari (Nash et al., 2013b; Nash et al., 2016), it may be useful to view these sites as snapshots of short-term human activity within a large and open landscape (see also Nash et al., 2022).

Unlike other excavated MSA sites in Botswana, the sites in Ntwetwe Pans have ready access to silcrete raw material. Likely as a result, tool production seems to our eyes as profligate, as large blocks of silcrete, flakes suitable for blanks, and points with only minor asymmetries were abandoned. There is also no evidence of resharpening or curation of tools, another indication of easy lithic raw material access. The dominance of points may have further implications. The highly retouched, large points common to Ntwetwe Pan were obviously unsuitable for darts or arrows but were basally thinned, likely for hafting. While these may have been intended for use as spearheads, there is limited evidence of impact fracturing at the excavated sites. In the case of MAK33, a plausible interpretation would be that the lithic production illustrates a short-term stop prior to moving to a hunting location, as exemplified by #Gi Pan in western Botswana (Brooks and Yellen, 1977; Helgren and Brooks, 1983). Together with interpretations of repeat behaviours at #Gi (hunting) and Rhino Cave (ritualized actions) this begs the question of whether site specialization was common in the Kalahari MSA. That two of these are open-air sites further emphasizes that examination of such sites can provide additional perspectives to those provided by cave sites. Future investigations into this area will likely provide data to situate the Makgadikgadi Pans archaeology within a refined regional chronology and link these to wider discussions on MSA mobility and migrations (see also Thomas et al., 2022). Notwithstanding, the Makgadikgadi sites presented here illustrate that MSA people successfully adapted to and inhabited the hydrologically dynamic Makgadikgadi basin and were familiar with their surrounding landscape and the lithic raw materials therein.

Author contributions

Sigrid Staurset: investigation, analysis, text and illustration contribution. Sheila Coulson: investigation, analysis, text and illustration contribution. Sarah Mothulatshipi: investigation, local knowledge, review & editing. Sallie Burrough: fieldwork, review & editing. David Nash: fieldwork, review & editing. David Thomas: Principle Investigator, fieldwork, review & editing. All authors have approved this manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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