



Post-depositional disturbance and spatial organization at exposed open-air sites: Examples from the Middle Stone Age of the Makgadikgadi Basin, Botswana

Sigrid Staurset ^{a,*}, Sheila D. Coulson ^b, Sarah Mothulatshipi ^c, Sallie L. Burrough ^a, David J. Nash ^{d,e}, David S.G. Thomas ^{a,e}

^a School of Geography and the Environment, OUCE, University of Oxford, South Parks Road, Oxford, United Kingdom

^b Institute of Archaeology, Conservation and History, University of Oslo, Blindernveien 11, 0315, Oslo, Norway

^c Department of History, University of Botswana, Gaborone, Botswana

^d School of Applied Sciences, University of Brighton, Lewes Road, BN2 4GJ, United Kingdom

^e School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa

ARTICLE INFO

Article history:

Received 30 November 2021

Received in revised form

31 August 2022

Accepted 11 October 2022

Available online 29 December 2022

Handling Editor: Danielle Schreve

Keywords:

Refitting

Chaîne opératoire

Silcrete

Post-depositional disturbance

Site taphonomy

Spatial organization

Exposed open-air site

Middle Stone Age

ABSTRACT

The influence of natural factors such as bioturbation or sediment movement caused by wind and water is a perennial concern for Stone Age site selection and subsequent interpretation. This paper discusses the spatial artefact distribution of five recently excavated, open-air exposed Middle Stone Age (MSA) sites in Ntwetwe Pan, Botswana. The finds comprise lithic assemblages dominated by MSA points, manufactured in a variety of silcretes. The sites were examined following the assumption that archaeological sites are the product of a combination of natural and cultural factors, occurring both during and after artefacts are deposited. The results indicate that some of these exposed pan floor sites do preserve cultural artefact distribution patterns, and that the level of post-depositional disturbance varies locally. Refitting was an important tool of analysis, especially on the largest site, MAK33, where it was possible to identify working areas that focussed on different modes of lithic manufacture. In combination with a *chaîne opératoire* analysis of lithic production stages, it was then possible to map movement of artefacts across the site. We argue that the spatial organization of open-air sites may preserve behavioural records that are not present at caves and rock shelters, and provide a view into the short-term, single-use locations that likely formed the basis of MSA occupation patterns.

© 2022 Published by Elsevier Ltd.

1. Introduction

The connection between Stone Age occupation and cave dwelling has been a stalwart of Palaeolithic archaeology since its infancy, and even today evidence from investigations of enclosed sites continues to dominate our understanding of prehistoric hunter-gatherer lifestyles. However, both archaeological and ethnographic studies document that hunter-gatherers are more commonly disposed to short-term open-air locales (e.g., [Aura, et al., 2011](#); [Forssman and Pargeter, 2014](#); [Kandel and Conard, 2012](#); [Lewarch and O'Brien, 1981](#); [Villa, 1982](#); [Yellen, 1990](#)), often as part of yearly or seasonal rounds to acquire resources from wide and

diverse geographic areas. In Africa, Middle Stone Age (MSA) research remains focussed on cave and rock shelters, although investigations of open-air sites are becoming more common, especially in areas where caves are rare (e.g., [Brooks, 1984](#); [Dietl et al., 2005](#); [Helgren and Brooks, 1983](#); [Knight and Stratford, 2020](#); [Shaw et al., 2019](#); [Wilkins and Chazan, 2012](#); [Yellen et al., 2005](#)). This development adds crucial and complementary angles to the range of Stone Age behaviours documented through cave research. Regardless of locale, archaeological sites are the combined result of prehistoric human actions and the variety of environmental factors that affected them after the inhabitants had departed.

One of the main attractions of cave sites is the prospect of protected undisturbed strata as opposed to the anticipated higher level of disturbance at open-air locations. As behavioural

* Corresponding author.

E-mail address: sigrid.staurset@ouce.ox.ac.uk (S. Staurset).

interpretations rely heavily on the integrity of archaeological layers and distributions, if these are found to be disturbed then the understanding of a given site can change dramatically (e.g., Cahen and Moeyersons, 1977; Dibble et al., 1997; Gifford-Gonzalez et al., 1985; Hofman, 1986; Romagnoli and Vaquero, 2019; Staurset and Coulson, 2014; Villa, 1982; Villa and Courtin, 1983). There is now ample evidence of post-depositional disturbance at cave and rock shelter sites caused by factors including bioturbation, soil formation processes, rock fall and trampling (e.g., Bailey, 2007; Bailey and Galanidou, 2009; Higham et al., 2011; Hunt et al., 2015; Staurset and Coulson, 2014; Stewart et al., 2012; Tribolo et al., 2010). Post-depositional disturbance can also affect open-air sites, where processes such as water and wind movement, erosion, modern construction, agriculture, and quarrying can be additional drivers of the redistribution and weathering of archaeological materials (e.g., Araujo, 2013; Knight and Stratford, 2020). Open-air sites may also be subjected to more extreme and fluctuating conditions, leading to the faster degradation of organic remains. Combined, these factors reinforce a belief that open-air sites are 'risky', not worth the effort of excavation and likely to be less informative than caves and rock shelters.

Open-air sites, however, comprise a large and varied range of environmental contexts and conditions. MSA examples encompass locations that include water-rolled artefacts redistributed along riverbanks, small artefact scatters likely reflecting short-term mobile camps, and deep, stratified sites documenting multiple repeat visits to especially attractive areas. While we acknowledge the challenges of investigating open-air sites, they can provide useful counterpoints to the more commonly investigated caves and rock shelters, particularly with regard to behavioural characteristics such as site usage and spatial organization. Caves and shelters are fixed points in the landscape, restricted by rock walls, whereas open sites permit direct proximity to resources and allow for a greater geographic spread of activity and interaction with the local environment. While enclosed sites tend to comprise cumulative

palimpsests accumulated over several millennia, where many episodes of activity can frustrate attempts to discern spatial clusters (e.g., Bailey, 2007; Stern, 1994), open locales are more likely to reflect limited prehistoric visits unless there was a specific reason to return to a particular location. It follows that open-air sites offer greater possibilities for the reconstruction of single visit intrasite spatial organization and its associated behaviours, without the blurring of repeated prehistoric visits characteristic of many cave sites.

In this paper, we present the results of investigations of the spatial organization and post-depositional disturbance of five exposed open-air MSA sites in Ntswetwe Pan, northern Botswana (see Fig. 1; and also Burrough et al., 2022; Coulson et al., 2022; Nash et al., 2022; Staurset et al., 2022; Thomas et al., 2022). These sites were fully excavated using *décapage* methods and the resulting lithic assemblages analysed using a *chaîne opératoire* approach with an emphasis on refitting (further reported in Coulson et al., 2022). Following a summary of the environmental setting of these sites and the archaeological methods used in their investigation, we assess the spatial distribution of the lithic assemblage at each site as a result of combined prehistoric human actions and natural post-depositional processes. A main goal was to assess the level of disturbance, and, following that, whether it was possible to determine the original lithic distribution and whether the level of disturbance was comparable at all locations. Furthermore, we wanted to investigate whether individual sites were used during single or repeated visits, such as the specialized hunting site at Gi Pan in northwest Botswana (Brooks et al., 2006; Helgren and Brooks, 1983). We argue that 1) refitting makes it possible to assess the impact of post-depositional disturbance on exposed sites, and 2) open-air sites such as those found across Ntswetwe Pan may preserve aspects of MSA spatial organization that did not occur in caves and shelters, and would not be recognized without total excavation.

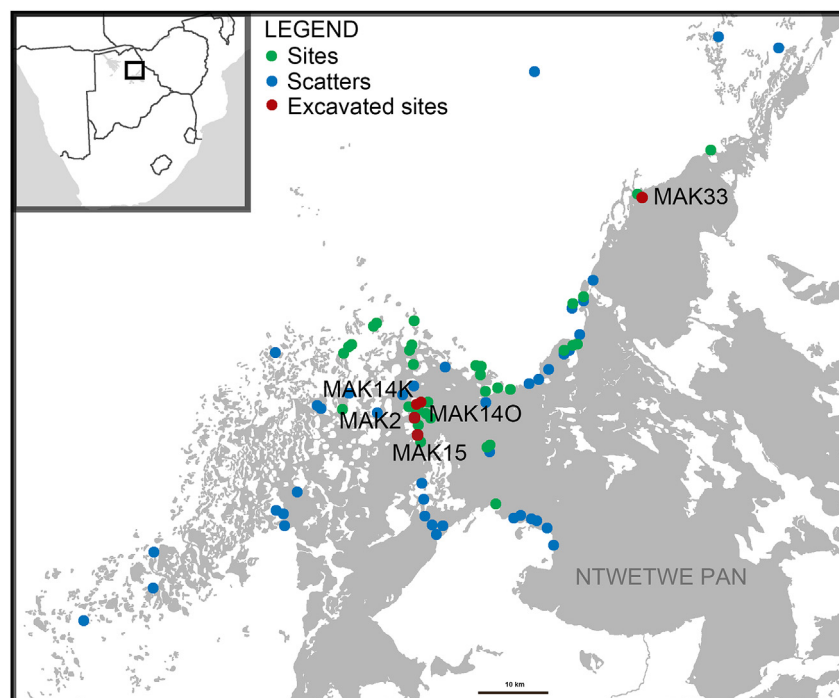


Fig. 1. The distribution of recently surveyed and excavated archaeological scatters and sites in the Makgadikgadi Basin.

2. Research area: Ntwetwe Pan and the Makgadikgadi Basin

2.1. Basin sediments and landforms

The saline sands and silts of the Makgadikgadi salt pans in the Middle Kalahari represent the remnant sump of a former palaeolake system and today extend across 16,000 km² of northern Botswana. Fed by rivers emanating from the north and the east, the contemporary Makgadikgadi basin and its associated fluvial systems are important zones of net erosion and sediment exposures within the wider Kalahari region, which is more typically characterised by deep sandy deposits that have accumulated since the Pliocene (Thomas, 1988; Haddon and McCarthy, 2005). Dust deflation is an important ongoing process; the pan surface constitutes the third largest source of dust in the southern hemisphere and is the most frequent dust emitter in southern Africa (Vickery et al., 2013). The two largest pans within the Makgadikgadi basin are Sua (or Sowa) Pan in the east and Ntwetwe Pan in the west. The western margins of the palaeolake are demarcated by broad, sandy shoreline ridges standing at 945, 936 and 920 m asl that formed during the largest lake high-stands in the late Quaternary (Cooke, 1980; Shaw and Cooke, 1986; Burrough et al., 2009).

The archaeological assemblages in this study are associated with sediments and landforms below 920 m asl within the central zone of Ntwetwe Pan. These sediments can be broadly categorised as i) siliclastic lacustrine deposits of mainly detrital quartz and authigenic clays, often covered by evaporite crusts; ii) sandy, aeolian deposits 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 Ntwetwe Pan up to a depth of approximately 1m. As seasonal rainfall or flood waters subside, a shallow water table in conjunction with strong evaporative losses maintains an overall negative water balance, encouraging the formation of consolidated evaporitic surface crusts mostly composed of halites (Eckardt et al., 2008). These crusts are dynamic over the course of a seasonal cycle, ridging and thrusting as the pan surface dries out (Nield et al., 2015), and are important for the supply of fine particles that contribute to mineral dust.

Monitoring of the hydrochemistry of Sua Pan over two wet seasons has shown that the pH of lake waters ranged between pH 8.6 and 10, with maximum values recorded during the initial phases of seasonal flooding when pre-existing salts in riverbeds or pan margins were dissolved (Eckardt et al., 2008; McCulloch et al., 2008). Such fluctuating pH conditions enable both the mobilization of silica (from quartz grains and biogenic silica sources such as diatoms; Ringrose et al., 2014) and its re-precipitation as consolidated silcretes, particularly within porous sandy sediments (see Nash and Ulllyott, 2007). Silcretes in Ntwetwe Pan occur both as small, low outcrops, mainly around the pan margins, and extensive lags of broken up material. Individual outcrops and fragments exhibit a variety of morphologies, in part depending upon whether the silcrete developed as a primary precipitate within lake sediments or via the replacement of a pre-existing calcrete (cf. Nash and Shaw, 1998; Nash et al., 2004). Primary silcretes are typically nodular, sheet-like or massive in appearance (Ringrose et al., 2014), with unusual tube-like silcretes also present that likely developed through the silicification of root structures. Silcretes that formed by replacement of calcrete have more irregular morphologies and, where exposed in palaeolake strandlines, may be lenticular in appearance. The range of colours exhibited by individual silcrete outcrops and fragments is equally variable. Most silcretes within Ntwetwe Pan are grey, off white, beige or pale brown in colour, but black silcretes are widespread in the eastern and southern pan, and

pale to dark green glauconitic silcretes occur at the northernmost margins (Webb and Nash, 2020).

2.2. Post-depositional disturbance and the 2016–2017 sites

The connection between sediments and post-depositional disturbance is a perennial and well documented topic within archaeology. Most discussions focus on vertical displacement (e.g., Gifford-Gonzalez et al., 1985; Hofman, 1986; McBrearty, 1990; Moeyersons, 1978; Schiffer, 1983; Villa and Courtin, 1983). However, at the MSA sites on the floor of Ntwetwe Pan, where the archaeological distributions appear shallow to the point of being virtually two-dimensional, horizontal disturbance is a greater consideration. As reported at other Kalahari Stone Age sites, biogenic activity and soil formation processes (e.g., Staurset and Coulson, 2014; Wilmsen, 1978; Yellen, 1977; Yellen and Brooks, 1989) commonly cause extensive post-depositional disturbance. The dry sandy deposits and plethora of burrowing animals in these environs contrasts to the wet, alkaline sandy silts and clays that constitute the Ntwetwe Pan floor, conditions that discourage animal burrows and termite mounds, and limit vegetation. Trampling from animals, especially ungulates such as zebra and wildebeest that are seasonally common in the basin, remains a potential factor (see Fig. 2), and the characteristic fragmentation pattern caused by this form of disturbance poses a relevant framework through which Kalahari MSA assemblages can be assessed (e.g., Eren, et al., 2010; Gifford-Gonzalez et al., 1985; McBrearty et al., 1998; Nielsen, 1991; Pargeter and Bradfield, 2012; Reynard and Henshilwood, 2018).



Fig. 2. Examples of natural disturbance factors in Ntwetwe Pan. A) Dune in Ntwetwe Pan illustrating size sorting of sediments and characteristic zone of approximately 1m around its margin that is empty of larger gravels or artefacts. Surveys documented several archaeological scatters in wash-zones beach-like formations probably disturbed by similar processes. B) Zebra tracks approaching site MAK33.

However, the most likely cause of artefact redistribution on the exposed archaeological sites within Ntswetwe is water action, manifesting in numerous extended 'beach-like' scatters often comprising evidence from several archaeological periods (see Fig. 2; Coulson et al., 2022; Staurset et al., 2022). The lack of small, thin (<1 cm) debitage at virtually all the exposed sites on Ntswetwe could be a result of winnowing caused by water movement, potentially in combination with wind erosion. The Ntswetwe Pan sediments differ from many Kalahari sand archaeological layers in that the local disturbance factors are more active on the surface (water, wind) rather than subsurface (bioturbation, sedimentary processes), though clay expansion and shrinkage and associated cracking of the surface sediments (Nield et al., 2015) may constitute a locally important disturbance process. Single grain OSL analyses (Burrough et al., 2022) from lake bed sediments associated with archaeological material suggest that sediment mixing can be variable even within sites but remains relatively low compared to mixing within younger overlying sands. The active nature of the saline lake sediments, where the surface clay crust can appear and disappear within a season (Staurset et al., 2022), in combination with repeated wetting and drying, has likely contributed to more localized blurring of artefact distributions (for an ethnographic example, see Gifford and Behrensmeyer, 1977). As the pan floor is uninhabited and undrivable for most of the year, pilferage and vehicular disturbance of exposed sites are less likely to occur.

Surveys of northern Ntswetwe Pan in 2016 and 2017 documented exposed sites with a wide variety of visible disturbance; these ranged from jumbled scatters of artefacts representing several archaeological periods to denser concentrations of MSA material where on-site initial refitting indicated the original spatial distribution was preserved. The five MSA sites selected for further investigation were chosen to accommodate all these elements and represent a range of sizes, but one main criterion was that surveys indicated limited post-depositional disturbance (for location see Fig. 1). A beneficial feature of the exposed sites on the floor of Ntswetwe is that it is possible to separate delineated sites and indistinct archaeological scatters, and distinguish both from the surrounding archaeological "background noise" (Brooks and Yellen, 1987) such as occasional spot finds exhibiting contrasting technological or raw material characteristics. Furthermore, the shallow nature of the archaeological spread rendered possible the full excavation of the selected sites by *décapage* within the constraints

of two field seasons. The finds are summarized in Table 1, while a description of the surveys, site selection, excavation procedure and assemblage characteristics can be found in Staurset et al. (2022).

3. Methodological approach: reconstructing the spatial dimension of MSA chaînes opératoires through refitting

3.1. Post-depositional disturbance and lithic assemblages

The excavated assemblages from the five MSA sites on the floor of Ntswetwe Pan were analysed using a *chaîne opératoire* approach with an emphasis on refitting. This analysis aimed to understand and characterize the local lithic technology and production (Staurset et al., 2022) and investigate the interaction between on-site behaviours and natural taphonomic processes. Key to addressing these questions was establishing contemporaneity and mapping horizontal artefact movement, both of which ideally could be explored through refitting. The intent of refitting is to reconstruct the original nodules from which flakes were struck (Cahen, 1987:1), thus recreating the physical manifestation of the sequence of actions undertaken by an individual prehistoric knapper. An artefact will only refit back to its original location: either it fits, or it does not. The practice of refitting necessitates the identification and memorization of a wide set of characteristics within a body of material. Through this process, the refitter also gains a thorough understanding of the pertinent chaînes opératoires, including technological approaches, techniques of manufacture and the conscious choices made by the original artefact makers (e.g., Coulson and Andreasen, 2020). This process allows interpretations to be made regarding behaviour patterns affecting the entire assemblage, including those that were not refitted. Which parts of an assemblage are selected for refitting can depend on a variety of factors including raw material properties, time constraints and the objectives of the analysis. The case has been made for attempting to conjoin large percentages of entire assemblages (Bar-Yosef and Peer 2009) or alternatively to target only elements judged to have the greatest potential to address specific questions (e.g., Coulson and Andreasen, 2020; Lyman, 2008; Schurmans, 2007). Given that the current interdisciplinary project focused on a series of specific queries regarding MSA landscape use and site formation, we employed problem-oriented refitting to test these. As one objective was the documentation of

Table 1

Overview of the five excavated MSA sites in Ntswetwe 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	Percentage refitted ¹	Main products	Artefact condition (level of weathering)
MAK2	Edge of small dune	24	38	Laminar(?)	3	16	• Points (late stages only)	Very fresh
MAK14K	Edge of small dune	42	88	Levallois, discoidal, Kombewa	3	9	• Points • Core preparation	Fresh to mint
MAK14O	Pan floor	100	555	Levallois, Kombewa, discoidal	13	9	• Points • Blanks • Core cleaning and preparation	Very fresh
MAK15	Edge of low, elongated dune	22.25	55	Levallois, laminar	4	18	• Points (late stages only) • Blanks	Very fresh
MAK33	Pan floor	430	3426 ²	Levallois, two platform	14	21	• Points • Blanks • Knives • Core cleaning and preparation	Very fresh to mint

¹ By refitted we here mean the total number of artefacts that have been refitted to at least one other artefact.

² This number includes a characteristic raw material group (M) with a tendency to produce shatter ($n = 775$), on which very little refitting was attempted.

the local MSA technology and how this relates to other regional industries, we further targeted for refitting the reduction sequences where most stages of the *chaîne opératoire* were present.

With the exception of rare, documented examples of scavenging, the archaeological reshaping of tools from earlier periods (Bamforth, 1990; Kelly, 1988; Schiffer, 1983; Vaquero et al., 2017), refitted artefacts are part of the same technological action sequence and therefore contemporaneous (Cahen and Moeyersons, 1977:813). This is one reason refitting is commonly used to investigate disturbance and potential admixture between layers at stratified sites (to name but a few, Bergman, et al., 1990; Cahen, 1987; Close, 2000; Hofman, 1981; Roebroeks et al., 1997; Villa, 1982). Although the application of refitting is not the only method for assessing the complex issues of contemporaneity and disturbance (for other approaches, e.g. Oestmo et al., 2014), it has the advantage of being applicable even in situations where depositional data are limited or only the archaeological assemblage remains available for analysis. This makes it an indispensable method for investigating exposed deflated sites, such as those in Ntwetwe Pan. Key to this process is being open to the possibility that a site has been shaped by natural, environmental factors, as well as cultural behaviours. Sediments are viewed as malleable elements through which artefacts “float, sink, or glide” (Villa, 1982:287), therefore most archaeological sites will have some level of disturbance. If several widely dispersed artefacts on a site refit with no obvious cultural explanation (e.g., moving tools for use elsewhere), the effects of natural factors such as bioturbation or soil formation processes should be explored. However, because these factors can affect deposits unevenly, a few refits of pieces found close to one another should not automatically be considered evidence of the undisturbed nature of a site as a whole (Staurset and Coulson, 2014). Disturbed sites can still yield large amounts of information, e.g., regarding typology or lithic production, but the impact of post-depositional factors on the assemblage must be assessed before any behavioural interpretations are made (Clark, 2017, 2019). Refitting has, in most instances, been used to assess vertical displacement (e.g., Deschamps and Zilhão, 2018; Hofman, 1986; López-Ortega et al., 2019; Romagnoli and Vaquero, 2019; Vaquero et al., 2017; Vaquero et al., 2019; Villa, 1982). Investigations of horizontal displacement are often limited by the size of the excavated area but can, in part, be supplemented by experimental data (e.g., Eren, et al., 2010; Marwick et al., 2017; McBrearty et al., 1998; Nielsen, 1991; Reynard and Henshilwood, 2018; Vaquero et al., 2019). While refits of artefacts that are separated vertically almost always signify post-depositional disturbance, horizontal separation of conjoined artefacts can also be caused by cultural factors at their time of deposition. Two well-documented examples from lithic production include flakes springing several metres from the core when struck (Barton and Bergman, 1982; Boëda and Pelegrin, 1985; Clark 2019; Newcomer and Sieveking, 1980; de la Torre et al., 2019) and the practice of moving select artefacts from one working area to the next for further modification (e.g., Karlin and Julien, 2019; López-Ortega, et al. 2019; Vaquero et al., 2019). Consequently, refitting investigations with a horizontal focus should take into account pertinent cultural behavioural patterns and potentially be used to further explore these.

Cultural disturbance factors can be amplified by repeated pre-historic visits to a site, leading not just to direct post-depositional artefact displacement through scuffage by foot traffic and activities such as digging or hearth construction, but to the formation of palimpsests where individual episodes of use can no longer be separated (Bailey, 2007; Bailey and Galanidou, 2009). In a Kalahari MSA context, such accumulated sites can be vital in investigating repeat specialized activities, such as hunting at ≠Gi Pan (Brooks et al., 2006; Helgren and Brooks, 1983) or ritualized behaviours at

Rhino Cave (Coulson et al., 2011). Conversely, single-visit sites can be used to reconstruct a fuller picture of activities undertaken during the limited period of time characteristic of most Stone Age excavations. When it comes to determining what to expect at ‘normal’ MSA sites (in terms of spatial organization, extent and variety of lithic production, size of assemblage etc.), single-visit sites may therefore offer a more accurate picture. Given that the Stone Age archaeology of the Makgadikgadi Pans was largely undocumented prior to this research project, the full excavation of single-visit sites was prioritized as they would likely be more representative and comprise less admixture from successive occupations. The floor of the contemporary Ntwetwe Pan has no preserved large and permanent landscape features that would have encouraged repeat MSA visits to specific locations. The exposed nature of its archaeological sites permitted an initial assessment of the artefact spread prior to excavation. We prioritized sites of a limited size and delineated extent, where artefacts appeared typologically cohesive and, in some cases, formed clusters that could reflect knapping scatters or working areas. On-site refit testing was undertaken during survey and – in cases where conjoined pieces were located close together – the sites were considered for excavation (Staurset et al., 2022). This initial indication of relatively low levels of disturbance at the sites chosen for further investigation (see overview in Table 1) was then tested through targeted refitting during the *chaîne opératoire* analysis of the lithic assemblage.

3.2. Methods of analysis

Following excavation, cleaning and labelling, the MSA lithic materials from the five Ntwetwe Pan sites were subjected to the methods of analysis and classification described in Staurset et al. (2022), of which a brief summary is given here. The assemblages were separated into silcrete 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) (see SOM1). This formed the starting point for identifying artefacts that likely originated from the same block (Larson and Ingbar, 1992; Larson and Kornfeld, 1997; Phillipps and Holdaway, 2016; Scerri et al., 2016), which were then tested and refined through refitting. The lithic analysis was undertaken in conjunction with refitting, as the latter method was vital to understanding the hitherto undocumented MSA technology of the Makgadikgadi Basin; refitting and classification was an interactive process (Clark, 2017; Soressi and Geneste, 2011).

Broadly, the excavated sites fall into three categories based on size of the horizontal spread and lithic assemblage (Table 1): small (MAK2 and MAK15), medium (MAK14K and MAK14O) and large (MAK33); they will be discussed in that order. The lithic assemblages from all five sites were characterized by the production of heavily retouched unifacial and bifacial points, produced either on natural blanks or on flakes originating in Levallois, Kombewa or discoidal reduction strategies. Tool types other than points were rare and in contrast to other Kalahari MSA sites the only raw material employed was silcrete (Coulson et al., 2022; Staurset et al., 2022). To avoid bias towards conjoining pieces located close together, the positional information of each artefact was disregarded during refitting, and their locations only mapped out after attempts had ended. This study was conducted by two experienced refitters (contributors SC and SS) over a combined total of 10 weeks, at the end of which the refitting process was still producing results.

Refitting was attempted on the material from all five sites but the largest site, MAK33, was prioritized (see Table 1). This was partially due to its larger sample population and potential for mapping out a wider horizontal distribution, but also because it

became evident during refitting that the individual production sequences at this site were the most complete. Within this assemblage we prioritized the eleven silcrete raw materials groups with the most complete production sequences (especially groups A, B, D and E) as these documented more fully the tool production processes characteristic of the MSA in this area. Conversely, refitting attempts were limited on one raw material group (group M), as the limited knapping attempts and the propensity of this silcrete to shatter rendered reconstruction of reduction strategies less productive. Combined, the prioritized groups comprised most of the area constituting site MAK33, which was an important prerequisite for understanding potential spatial organization. At the medium-sized sites (MAK14K and 14O), refitting attempts were constrained after it was determined the production sequences were disjointed. Refitting attempts were also undertaken at the two final sites, MAK2 and MAK15, where the small sample population curtailed extensive conjoining.

All five sites were fully excavated, and exposed artefacts in the surrounding area were surface collected and registered within the same grid. This provided two major benefits to refitting analysis. First, the resultant assemblage was as complete as possible, and second, potential artefact movements could be mapped out across entire MSA sites. Patterns of artefact organization and/or movement that had affected the distribution should therefore be observable through the mapping of refitted core reduction sequences. This combination of total excavation and refitting also permitted further exploration of aspects such as import of lithics at various technological stages to each site, whether raw material blocks were worked at several locations, how much space was used for toolmaking and the potential interaction between different working areas. The current body of research on open-air MSA site organization is limited (but see e.g. Dietl et al., 2005; Fuchs et al., 2008; Knight and Stratford, 2020; Shaw et al., 2019) but potential parallels include experimental lithic production (e.g., de la Peña and Wadley, 2014; Mourre et al., 2010; Villa et al., 2009), ethnographic studies of Kalahari hunter-gatherer activity areas (e.g., Bartram, et al., 1991; Brooks, 1984; Brooks and Yellen, 1987; Clark, 2017; Clark 2019; Kroll and Price, 1991), and Upper Palaeolithic open-air sites with preserved specialized tool production areas (Anderson et al., 2018; Karlin and Julien, 2019; Olive, 2004). These perspectives can only be investigated after the level of post-depositional disturbance has been assessed and determined not to have obliterated the original spatial distribution. Prior to these excavations it was anticipated that the Ntvetwe Pan environment, which has undergone repeated wetting and drying, active sedimentation and deflation, and regular herd animal migration, would likely result in a gradual blurring of lithic concentrations with local areas of more intense artefact movement caused by bioturbation. Even though the sites selected for excavation displayed few indications of disturbance, the documentation of potential artefact movement through refitting was therefore crucial.

4. Refitting and artefact distribution mapping: determining the extent of post-depositional disturbance and potential spatial organization

The five fully excavated MSA sites on Ntvetwe Pan were selected with the intent of representing a variety of sizes and landscape contexts while exhibiting few indications of post-depositional disturbance. Where relevant, we investigated the horizontal distribution of artefacts according to the spread of the

entire assemblages, raw material groups, cores, and tools¹ and refits. If artefact distributions or concentrations did not correspond with either of these technological categories, the site would likely have undergone substantial post-depositional disturbance. Larger refitted groups were examined further with regard to whether the distribution followed the reduction sequence. For example, if a series of refitted flakes were to be plotted in the order of removal, major changes in their recorded location should follow this order and not jump haphazardly between seemingly random areas. We also considered it likely that separate types of refits could have different implications: a single relocated flake in a sequence could have been moved intentionally for further modification or use, and therefore reflect prehistoric behaviour. Mends or conjoined breaks are normally considered accidental, and broken pieces may be less likely to be intentionally moved relative to tools. Levels of disturbance can vary locally, and as evidenced by our earlier refitting of Kalahari MSA lithics (Staurset and Coulson, 2014), the presence of a few refitted pieces located close to one another may not represent the integrity of the site as a whole. As this investigation represents the first attempts at refitting in Central Botswana, as well as the first excavated sites in Ntvetwe Pan, it was essential to keep an open mind concerning how this hydrologically active environment affected the archaeological distributions.

4.1. MAK2 and MAK15

The two smaller excavated sites, MAK2 and MAK15 (see Table 1 and Fig. 1) covered less than 25m² each, yielding respectively 38 and 55 lithic artefacts (see Fig. 3). Both sites were associated with the edges of dunes or sand patches on the pan floor; trenches were dug into these features to sample sediments for OSL dating. At each site, a single flake was recovered beneath the sand mound at the same level as the remainder of the finds, confirming that the dunes were deposited more recently than the MSA sites (Burroughs et al., 2022). The assemblages could be sorted into three (MAK2) and four (MAK15) silcrete raw material groups based on hand specimen characteristics (see SOM1). Both assemblages were in very fresh condition with few indications of weathering other than a very slight blunting of the dorsal ridges (as defined by the following: Burroni et al., 2002; Bustos-Pérez et al., 2019; building on original documentation by Shackley, 1974; see also Staurset et al., 2022). MAK2 yielded a number of points, including two distinctive, highly retouched bifacial examples that had both broken near the tip during manufacture (Staurset et al., 2022), while MAK15 had several large laminar flakes, likely intended as blanks. At both sites knapping efforts were restricted to later stages of the *chaîne opératoire* of point production and, considering the small assemblage sizes, probably represent brief re-tooling episodes.

The distribution of the raw material groups and corresponding refits can be seen in Fig. 3. We could not identify any cultural clustering of artefacts based on general spread, raw material groups, cores or tools. While the number of artefacts recovered from these sites are limited, it appears likely that the original distribution of both assemblages has blurred due to geomorphic or sedimentary processes. At MAK15 the distribution of artefacts appears roughly parallel to the dune edge. This phenomenon, which as noted above is likely the result of dunes acting as a barrier to water/wind induced artefact movement, tends to result in a wash-zone of coarser material with a characteristic empty zone adjacent to the dune edge. Further, the assemblage analysis indicated that the local *chaînes opératoires* were disjointed, confirmed by the small number of refits identified at both sites. The limited number of refits do, however, demonstrate horizontal movement of c. 16m distance at MAK2, and several instances of movement of c. 7m at MAK15. As most of the refits from these two sites are mended

¹ Here, the category of cores include core fragments; retouched pieces include any artefact with a retouched edge, including broken tools, and point roughouts.

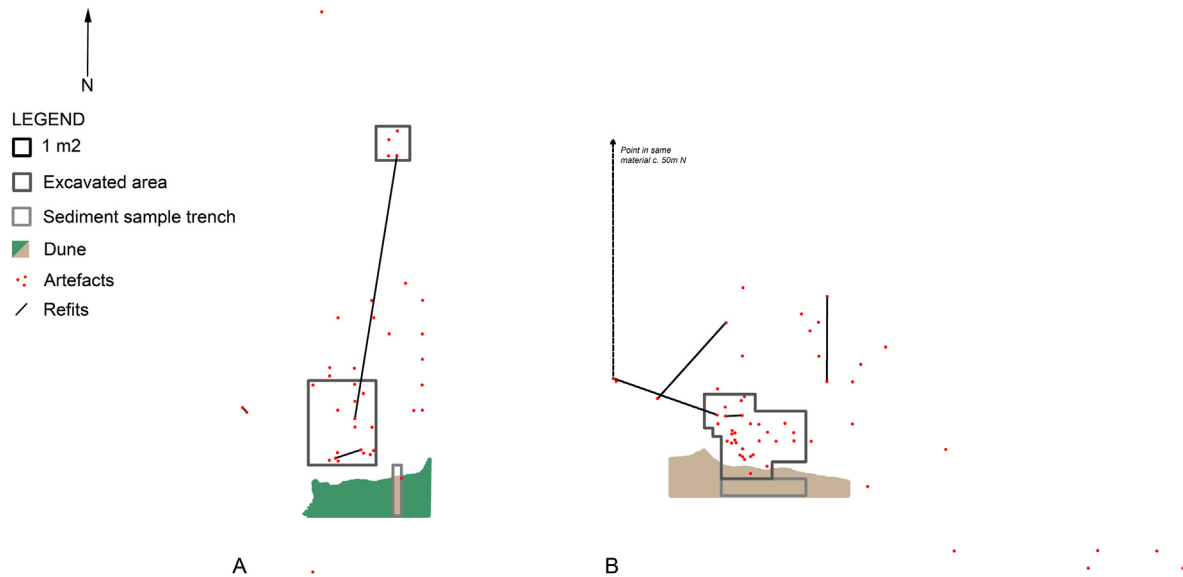


Fig. 3. Plan view of the distribution of lithic finds and refits from sites MAK2 (A) and MAK15 (B), Ntwetwe Pan. Lines between refits indicate shortest horizontal distance between pieces, not order of removal.

broken pieces, it is very unlikely this change of location represents cultural choice. Tentatively, MAK15 has experienced less disturbance than MAK2.

4.2. MAK14K and MAK14O

North of MAK2 and MAK15 we documented MAK14, an unusually rich area of c. 250 × 600m comprising 15 archaeological sites and scatters as well as numerous loose finds. The underlying sediment in the MAK14 area featured numerous sections of hardened clay surfaces, sometimes slightly elevated relative to the pan floor (Staurset et al., 2022). Two sites in this area, MAK14K and MAK14O, were fully excavated during this project. **MAK14K** comprised 88 artefacts from the 42 m² excavated area and surface collected from the immediate surrounding area (see Fig. 4). In common with the two smaller sites discussed in section 4.1, this site was associated with a small dune, and during OSL sampling, a single flake was recovered beneath this dune at the same level as the remainder of the site. In contrast to the two smaller sites, the flake located beneath the sand mound was less weathered than the exposed lithic material, indicating that the overlying deposit afforded some protection from the elements. As can be seen in Fig. 4, there is some correlation between the artefact distribution

and the edge of the dune, with an artefact-free zone of c. 1m around the periphery. As noted with regard to MAK15, the presence of a topographic rise such as a dune can aid the formation of wash-zones, which may explain the artefact spread nearest to the dune. The underlying sediment at this site also featured a section of hardened clay within the central excavated grid, level with the basin floor. Notably, no artefacts were found on top of the hardened clay, and there is a virtually empty area located south of this natural feature. The majority of the artefacts were clustered north of this empty area, with a limited number of outliers in the surrounding area and a small scatter to the south.

Most of the MAK14K assemblage comprises a silcrete with patches of glassy and coarser material (raw material group A; for descriptions of all raw material groups see SOM1), which was spread across the site. The smaller raw material groups generally followed a similar distribution, but their numbers were too small to make definitive statements. However, if all raw material groups are included and we limit the plots to retouched pieces (see Fig. 4B), the distribution is much more localized, with a distinct clustering of retouched artefacts adjacent to the hardened clay section. This concentration could appear to reflect natural accumulation of artefacts around the hardened clay area due to sediment movement, except that this clustering is not replicated in the assemblage at

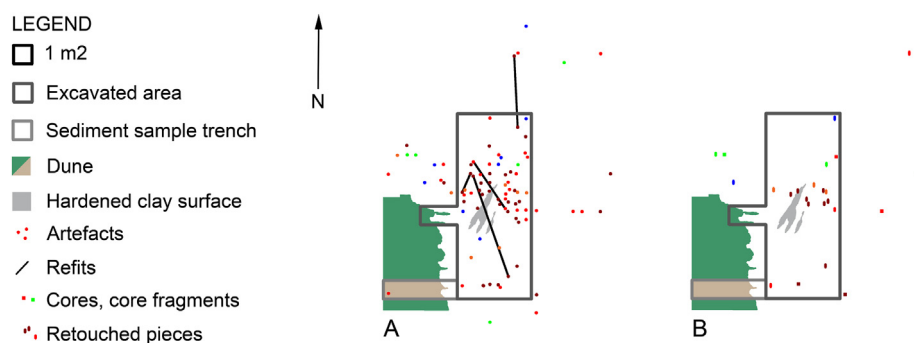


Fig. 4. Plan view of the distribution of lithic finds and refits from site MAK14K, Ntwetwe Pan. Different colours indicate different raw material groups. A: distribution of all lithic finds and debris. Lines between refits indicate shortest horizontal distance between pieces, not order of removal. B: distribution of cores/core fragments and retouched pieces (tools and tool fragments). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

large. More likely, the current distribution of the retouched pieces indicates the approximate working area where the final stages of retouched tools, chiefly points, were worked. Conversely, cores and core fragments only feature outside this cluster. This distribution outside of a main cluster may reflect the discard of exhausted examples, while partially worked cores were removed from the site along with finished tools. This strongly indicates that transport of cores and blanks was an inherent part of lithic production in the Makgadikgadi MSA (see also Nash, et al., 2022). While more stages of the *chaîne opératoire* are present at MAK14K compared to the smaller sites (section 4.1), there are no indications of core cleaning or evidence of full reduction sequences from core to blank to tool. Once again, the number of refits is limited, likely due to the disjointed local production sequences. The refits do however connect the looser southernmost scatter at the site (best seen on Fig. 4A) to the main artefact cluster. The shorter maximum distance of refitted pieces (c. 6m) likely reflects the more concentrated lithic distribution at MAK14K, indicating that there has been less post-depositional disturbance than at MAK2 and MAK15.

The second medium-sized excavated site, **MAK140**, was located c. 150m north of MAK14K. This larger excavation covered 100m,² more than twice the size of MAK14K, and yielded an assemblage more than six times larger (Table 1). Two edges of the site were bordered by landscape features approximately 5 m from the grid (see Fig. 5): a hardened clay platform elevated approximately 20 cm above the basin floor and a grass-covered dune. During surveys, this site was flagged as highly promising, due to apparent knapping clusters and abundant debris. Core fragments that were refitted during survey, located less than 2 m apart, indicated the possibility of preserved spatial organization. After analysis, it was evident that the assemblage was dominated by one type of black silcrete (raw material group A, see SOM1), which was worked with a consistent pattern of production techniques. This group comprised stages of the *chaîne opératoire* including the initial testing of a raw material block, core cleaning, blank production and discard of exhausted cores. Additional smaller raw material groups tended to represent either finishing stages of point manufacture or abandonment of rejected examples. Our initial field assessment of preserved knapping clusters was not mirrored in the artefact distribution plots (see Fig. 5). These plots reveal a blurred spread with no obvious

concentrations, appearing to fan away from the hardened clay platform. Nor could any obvious clustering be identified based on the distribution of raw material groups, retouched pieces, or cores. The 4–5m zone bordering the platform and the dune was virtually artefact-free, likely caused by the same factors noted previously regarding the interaction between water and local landforms. However, while these plots indicated that the original artefact placements had been disturbed, we had as yet no indications of the extent of post-depositional movement.

Refitting analysis, which prioritized raw material group A, supplemented these results by documenting the distance and direction of movement of artefacts (see Fig. 5). This demonstrated a combination of movement over both longer and shorter distances, ranging from pieces of a broken core found c. 14m apart to dorsal-ventral flake refits separated by less than 1m. Two notable examples, both from raw material group A, illustrate this variability. Firstly, two pieces of a Janus flake, split by a *siret* break, were located 8m apart; the Kombewa core to which they refit was recovered respectively 6 and 8m from them. As these characteristic breaks are knapping errors there is no apparent cultural explanation for the diverging placement of the resulting pieces. Secondly, the abovementioned four core fragments refitted during survey were later supplemented by an additional “window” flake used for testing raw material quality (see Staurset et al., 2022 for illustrations). The core fragments, which had split along natural fracture planes following an early removal blow, were located less than 2m apart; the “window” flake was found c. 3m from them. This illustrates a brief knapping sequence of initial removals where the pieces, including the small flake, remained at, or near, their original placement. Potentially, this could be explained by the fragmented core sequence being the result of a later visit to the site, thus being subjected to disturbance factors for a shorter time period. However, the consistency of the raw material characteristics and the techniques with which they have been worked both strongly indicate short-term single use of the site. Combined, these two examples illustrate that the level of post-depositional disturbance can vary significantly within a few square metres, highlighting the importance of local factors.

While the number of refits from MAK140 are limited, their direction of movement is consistent with a pattern of fanning away

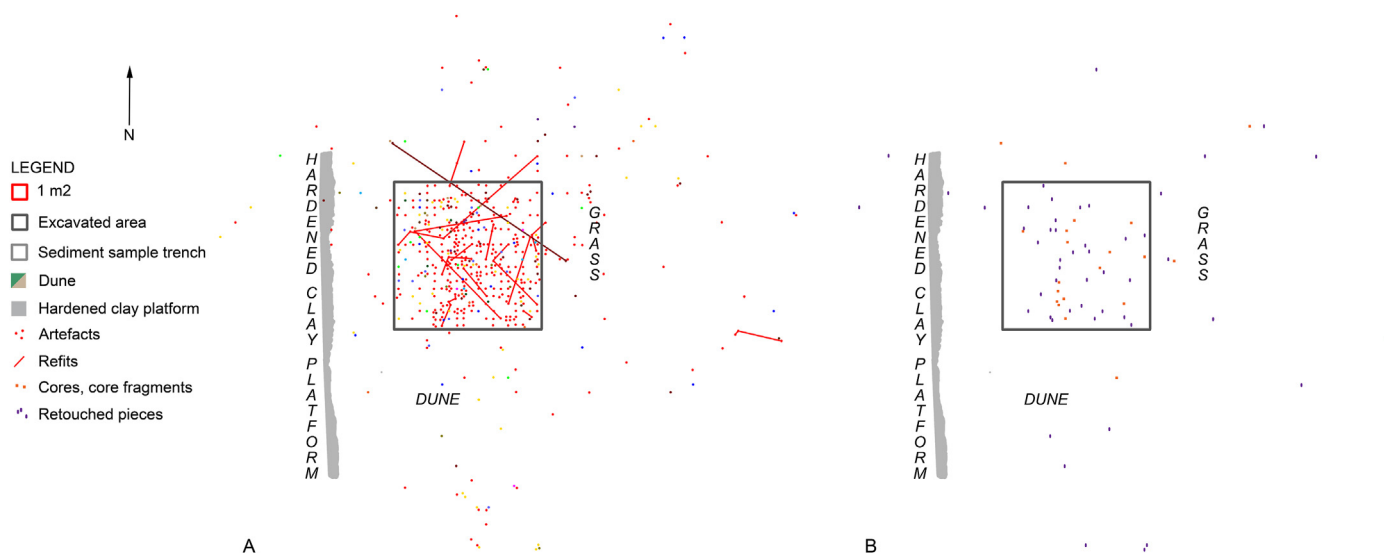


Fig. 5. Plan view of the distribution of lithic finds and refits from site MAK140, Ntwetwe Pan. Different colours indicate different raw material groups. A: distribution of all lithic finds. Lines between refits indicate shortest horizontal distance between pieces, not order of removal. B: distribution of cores/core fragments and retouched pieces. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

from the hardened clay platform and grass-covered area. This strengthens the interpretation that adjacent landforms affect the post-depositional spread of exposed pan floor sites, although with varied intrasite impact. Notably, the distribution of artefacts at MAK14O and MAK14K, located only 150m apart and under what appears today as identical conditions, exhibit distinctly different patterns of preservation. This further emphasizes the local aspect of post-depositional disturbance on the basin floor, and the importance of testing what may appear to be preserved knapping clusters by refitting.

4.3. MAK33

4.3.1. MAK33: site description

MAK33, located near the present edge of the northern, narrower section of Ntwetwe Pan (see Fig. 1), is situated in a slightly elevated area (908 masl) relative to the general pan floor further east (904–906 masl). This was the largest excavated site and was prioritized for several reasons: the exposed artefacts were in very fresh condition, there were apparent preserved knapping clusters, and refits were found during surveys. A total of 430 m² was excavated, while an extensive surrounding area was surface collected within an extended site grid (Fig. 6). Unlike the sites described above, MAK33 was not associated with any present landforms. The sediment was predominantly composed of very fine to fine sands (see Burrough et al., 2022 for further details), and the central area of the site was bisected by a surface salt rind, which marked the margin of finer grained sediments (Fig. 6). The excavation focussed on the largest visible concentrations of artefacts, which correlated broadly with the occurrence of a patchy, hardened surface, cemented by a mixture of silica and clay, hereafter referred to as a “silica/clay hardground.” This silica-clay aggregate occasionally adhered to artefacts (see Fig. 7) and was virtually impossible to remove. Most of the area of silica/clay hardground was buried beneath a shallow surface sediment cover, with small areas protruding c. 1–3 cm above this cover. The presence of the silica/clay

hardground likely contributed to keeping the excavated area somewhat firmer and drier than the remainder of the site. Due to the presence of the silica/clay hardground or densely packed clays, excavation was normally discontinued either at the surface level or 1–2 cm below. Where feasible, excavation was continued to a maximum depth of 5–10 cm; this included areas beneath several of the exposed artefact concentrations. As can be seen in Fig. 6, a significant number of exposed artefacts were recovered outside the excavated area, considerably expanding the size of the space potentially used in prehistory. Trowel-probing of the underlying deposits in the surface collected area did not yield subsurface archaeological material, in contrast to a small number recovered within the excavated zone.

To facilitate discussion of this substantive site, the three areas comprising more dense artefact spreads will hereafter be referred to as West, North and South (see Fig. 8). Within MAK33 West, several potential knapping areas were identified, comprising debris, cores and tools in various stages of manufacture. Analogous lithic material was found in both MAK33 North and South, but here concentrations were markedly more diffuse (MAK33 South) or lacking (MAK33 North). Notably, the silica/clay hardground was only found in area MAK33 West, indicating a correlation between this sediment feature and denser artefact concentrations. Following recent classification of other common raw material types (Burroni et al., 2002; Bustos-Pérez et al., 2019; building on original documentation by Shackley, 1974), the surface level artefacts from this site were uniformly very fresh. However, the subsurface lithics (N = 27), some of which could be refitted to those from the overlying sediment, were in mint condition. This indicates that even a few centimetres of sediment cover protected these buried artefacts relative to the exposed archaeological material.

Two probable post-depositional disturbance effects were observed in the field at MAK33: size sorting and animal trampling. Small (less than c. 1 cm) artefacts such as platform preparation and retouching flakes were seldom found at exposed sites on the pan floor, presumably due to erosional processes (Staurset et al., 2022).

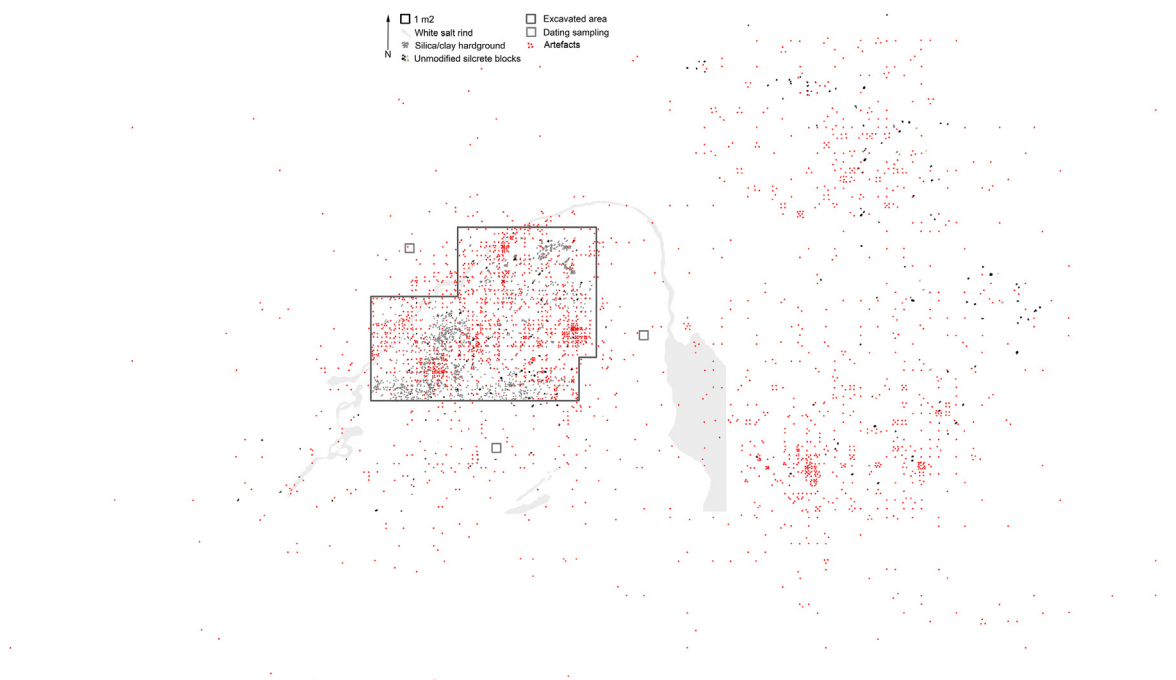


Fig. 6. Plan view of MAK33, Ntwetwe Pan showing natural features and distribution of all lithic finds.



Fig. 7. Three views of a broken MSA point from MAK33, Ntwetwe Pan. The point is partially embedded in a piece of the local silica/clay hardground, illustrating typical occurrence of this aggregate and its adherence to lithic materials. The tip of this unfinished, unifacial point had snapped off and was recovered c. 50 cm away from the base.

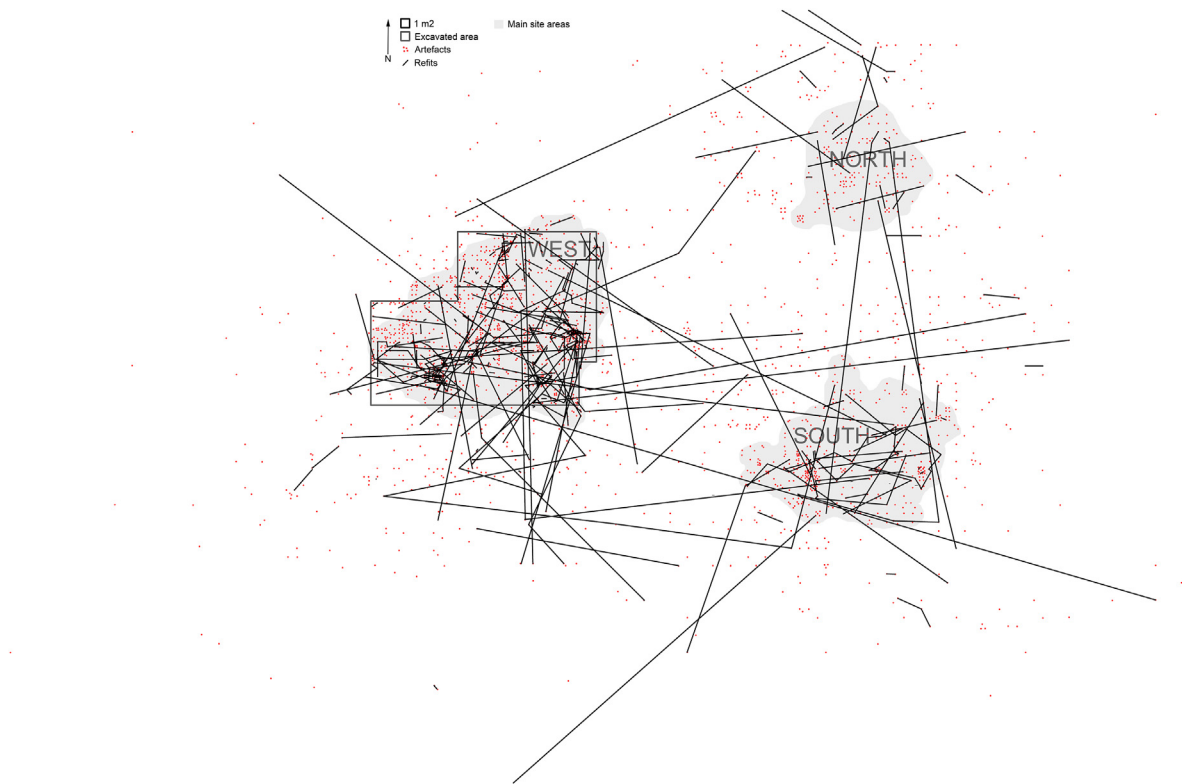


Fig. 8. Overview of artefacts and refits on site MAK33, Ntwetwe Pan, showing connections between different areas within the same site. Lines are drawn between refitted pieces, and where more than 2 pieces refit the shortest distance between these have been illustrated. The main site areas (MAK33 North, West and South) are also illustrated.

These artefacts were also absent in the subsurface layer at MAK33, meaning that the process had taken place prior to the site being covered with sediment. However, a loose scatter of debitage, c. 1 cm in size, was noted parallel to a section of the salt rind running north-west in MAK33 West (see Fig. 6). It appears likely that after the site was exposed, seasonal flooding has size sorted and redistributed some of the smaller-sized archaeological material. This

correlation artefact disturbance and a delineated surface feature was restricted to this narrow 7m area and not observed elsewhere on the site.

The second post-depositional factor, animal trampling, was anticipated as a major cause of disturbance at all the exposed basin floor sites. During survey, tracks from migratory animals were observed to cross parts of site MAK33 (see Fig. 2). Here, zebra had

passed in a south-north direction, skirting the north-eastern edge of the silica/clay hardground in MAK33 West, thus avoiding the lithic concentrations. This could be an example of how hoofed wild animals tend to avoid rocky terrain with sharp stones to avoid discomfort and potential lameness (pers. comm. 2020 from Christopher Pollitt and Brian Hampson² to contributor SC). The sediment was soft enough that in the few instances where zebra tracks contained artefacts, the lithic was pushed further into the wet deposit but had not been damaged. However, one rare example of a broken artefact was recovered at surface level near these tracks: an unifacial point where the base was embedded in silica/clay aggregate, while the tip was found 50 cm away (see Fig. 7). As this break was a fresh, dorsal-ventral snap, a recent trampling occurrence is a likely cause. It should be stressed that this was the only indication of probable animal-induced breakage recovered from this site. Similar to the other excavated assemblages, the MAK33 lithic material did not display the highly fractured nature characteristic of extensive trampling.

The possibility that MAK33 was not contemporaneous but the result of repeated, blurred episodes of use was considered throughout the analysis process. This interpretation could, in theory, explain the unusually large size of the site and the presence of three areas with denser artefact spread. However, this interpretation would fail to explain both the consistency of technological/knapping characteristics across the site and the lack of widespread blurring that commonly occurs by scuffage from repeated visits. It should also be noted that while MAK33 is unusual in an MSA context, there are examples of European Middle Palaeolithic open-sites covering 207–1928 m² (Clark 2019). Additionally, a series of repeated visits would suggest the presence of a highly attractive aspect to this particular non-descript location on the pan floor, which we at present cannot identify.

4.3.2. MAK33: refits and relocated artefacts

The MAK33 assemblage was initially sorted into raw material groups based on hand specimen characteristics; these groups formed the basis for the refitting investigation and were further refined throughout this process. All but one of the raw material groups comprised silcretes exhibiting conchoidal fracture (see SOM1 for an overview of the groups and their characteristics), the exception being group M, a distinctive material with a propensity to shatter. Attempts to refit this group confirmed that while numerous shatter fragments were recovered, actual lithic production was limited, probably due to the poor quality of the material. Refitting of the remaining raw material groups comprised several sequences that were surprisingly complete (i.e., few artefacts are missing), and these efforts successfully reconstructed knapped blocks as well as minor refits and conjoined breaks (see overviews in Figs. 8 and 9). Combined, these results indicate where many of the cores were originally worked. Further, they show that some refitted artefacts have relocated from the place where they were originally struck, linking areas MAK33 West, North and South, as well as some additional zones. The refitting process also revealed a high degree of hand specimen characteristic variability within individual blocks of raw material, in particular from groups A, B, D and E, thereby negating the possibility of exploring spatial behavioural patterns further on the basis of the distribution of these groups. A more productive approach was offered by mapping out refitted blocks from within the raw material groups; such mapping illustrates both where knapping likely took place and which artefacts had been

relocated. The full range of refits and behavioural interpretations for this assemblage will be presented in a future publication, however, for the purposes of this study five examples (see Fig. 9 for site locations) are discussed in detail, representing the variety of core reduction approaches, raw materials and site areas.

The first block, a **Levallois reduction sequence on a cobble** (raw material group E), comprises 36 pieces and two stages of single preferential flake removals. The refitted sequence includes the following knapping stages: decortication; preparation for the first preferential Levallois flake; detachment of said flake (plunged); preparation for the second preferential removal. The second preferential removal and the remainder of the core were not present on the site. Summarized, this refitted sequence illustrates the introduction of a natural cobble to the site, where numerous flakes and one Levallois removal were produced, before the remaining half of the block was removed, presumably for continued work elsewhere. The majority of the refitted pieces cluster within 2 × 2 m (Fig. 9), indicating that the core was knapped in the south-eastern section of MAK33 West. A small number of refitted artefacts were recovered some metres further out, while five artefacts were found at a significant distance (c. 12–35 m) further south and in MAK33 South.

The second block, a **Levallois core on an angular block** (raw material group A), comprises 15 artefacts and several preferential sequences. The refitted block includes the following knapping stages: preparation for a Levallois flake; detachment of said flake; preparation for a second Levallois flake (this removal was not present on site); partial preparation for a third preferential removal; final abandonment of core. Prior to this refitted sequence the core had been decorticated, and at least one Levallois flake had been removed. In addition to the preferential removals, a number of large flakes suitable as blanks for point production were detached – several ‘gaps’ in the refitted block with no corresponding flakes on site indicate that these were selected for use and removed. In short, a previously worked Levallois core was introduced to the site, several flakes and Levallois removals (some of which were moved away) were detached, and the core was subsequently discarded. This refitted sequence clusters less tightly, with the majority of flakes and the core located in the north-eastern edge of MAK33 West; three pieces were located further afield at distances of c. 18 m, 30 m and 40 m from the core (see Fig. 9).

The third block, a **two-platform, fragmented core** (also raw material group A), joins 20 artefacts and illustrates a less formal approach. The core was a tabular block of silcrete with two corticated surfaces. Prior to the refitted sequence, the first platform had been used for removal of at least one elongated flake (not found on site). The following technological stages were present: partial decortication/preparation of the initial platform; removal of (hinged) flake; preparation of a new, opposing platform; removal of elongated flakes (one of which was not found on site); the core then fractured into multiple, angular pieces. In summary, a previously worked core was introduced to the site, the flaking surface of which was then destroyed by a hinged detachment. Following this a new platform was prepared, several elongated flakes removed, before internal weaknesses caused the core to disintegrate. As can be seen in Fig. 9, the refitted artefacts cluster tightly within 2–3 m. Two small angular pieces were located some metres northwest of the cluster, within the salt rind zone (see section 4.3.1 above), and a single broken flake was found in the northern end of MAK33 West, approximately 13 m away.

The fourth block, **two cores deriving from a fractured block** (raw material group D), which comprises a total of 22 artefacts and originated as a single tabular piece of silcrete, illustrates a similar technological approach. This block fractured along a line of weakness, and while we cannot tell where this break occurred, both pieces were worked on site in proximity. The smaller fragment had

² Comments received November 2020 from Emeritus professor of Equine Medicine Christopher Pollitt, University of Queensland, and Brian Hampson, PhD Biologist.

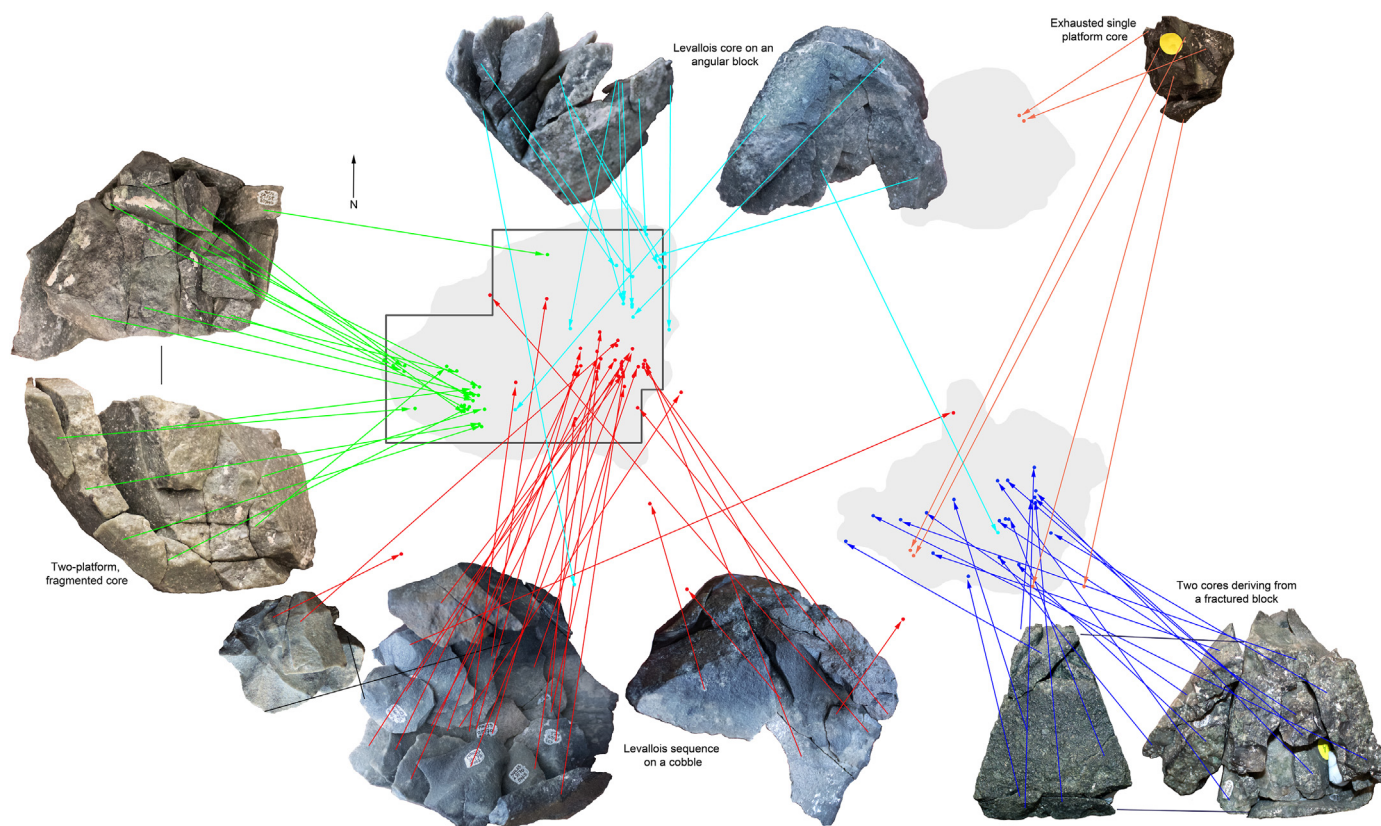


Fig. 9. Five refitted silcrete blocks from site MAK33, Ntwetwe Pan, also shown in Fig. 10 below. Arrows indicate the location of individual artefacts. Black lines between pictures indicate these are views of the same refitted blocks. The blocks are further described in the text.

one platform, from which several elongated flakes were removed. The larger fragment shows the following knapping steps: an elongated piece fractures off following another internal line of weakness; the first platform is prepared (these flakes were not found on site) and abandoned; an opposing platform is prepared; several elongated, stepped flakes are removed; the core is discarded. In summary, a block of silcrete fractured in two (likely on site), and elongated flakes were removed from both pieces – in the case of the larger fragment, two opposed platforms were employed. As can be seen in Fig. 9, all the refitted pieces in these blocks were found in MAK33 South, which was surface collected. The artefacts were located c. 2–11m from the cores, further than the examples from MAK33 West. In this instance, we have no evidence of refitted artefacts relocated outside the site area.

The fifth and final block, an **exhausted single platform core** (raw material group G), combined just six pieces from the final reduction of a small core. The following technological stages are present: detachment of bottom of core; detachment of several flakes; core is discarded. Multiple previous flake scars indicate prior removals. In summary, this refitted group illustrates the final stages of flake production and subsequent discard of a single platform core. As can be seen in Fig. 9, the refitted pieces in this block are divided between areas MAK33 North and South, with the core and the final flake located in the former area. The two pieces in MAK33 North are located in the same 1m², the flakes in area South are c. 1–15m apart, and the maximum distance between North and South pieces in this group is c. 45m.

Three main inferences can be drawn from the five examples. First, the refitted pieces are not randomly spread across the site, but anchor in separate geographic areas. For most of the sequences it is possible to ascertain the likely original knapping location. Second,

the distances between refitted artefacts are generally greater in MAK33 North and South than in MAK33 West, a trend reflected in the overall artefact spread (see Fig. 9). This is likely related to the underlying sediment, where MAK33 West features a silica/clay hardground not found in the remainder of the site. Third, four of the refitted groups comprise some artefacts that have relocated over considerable distances, up to c. 50m. These pieces are arguably the most useful indicators for considering probable causes for movement (summarized in Fig. 10). The most likely natural factors that would cause movement of artefacts on the pan floor are wind and water, which tend towards size sorting of exposed material. Cultural movement of artefacts tends to be purposeful and emphasizes usefulness, where the relocated pieces belong to specific technological or typological categories. Within the **Levallois reduction sequence on a cobble**, the three pieces that have relocated to the zone south of MAK33 West comprise a large, thick, plunged Levallois flake, a medium-sized hinged flake and a partial flake with a *siret* break; the two relocated to MAK33 South are a blank and a small broken flake. Three long distance refits are found within the **Levallois core on an angular block**: a naturally backed blank further south in MAK33 West, another partial flake with a *siret* break in the zone south of this area, and finally a well-prepared blank in MAK33 South. The **two-platform, fragmented core** comprises only one long-distance refit, a broken flake found in the northern end of MAK33 West. The three pieces that have relocated to the salt rind zone west of the likely knapping location are all small, angular fragments of similar size and shape. The distribution of the refitted pieces from the **two cores deriving from a fractured block** is generally more widely spaced but has no clear outliers. The two longest-distance refits are a broken flake and a rejuvenation flake. Lastly, the pieces comprising the **exhausted single platform**

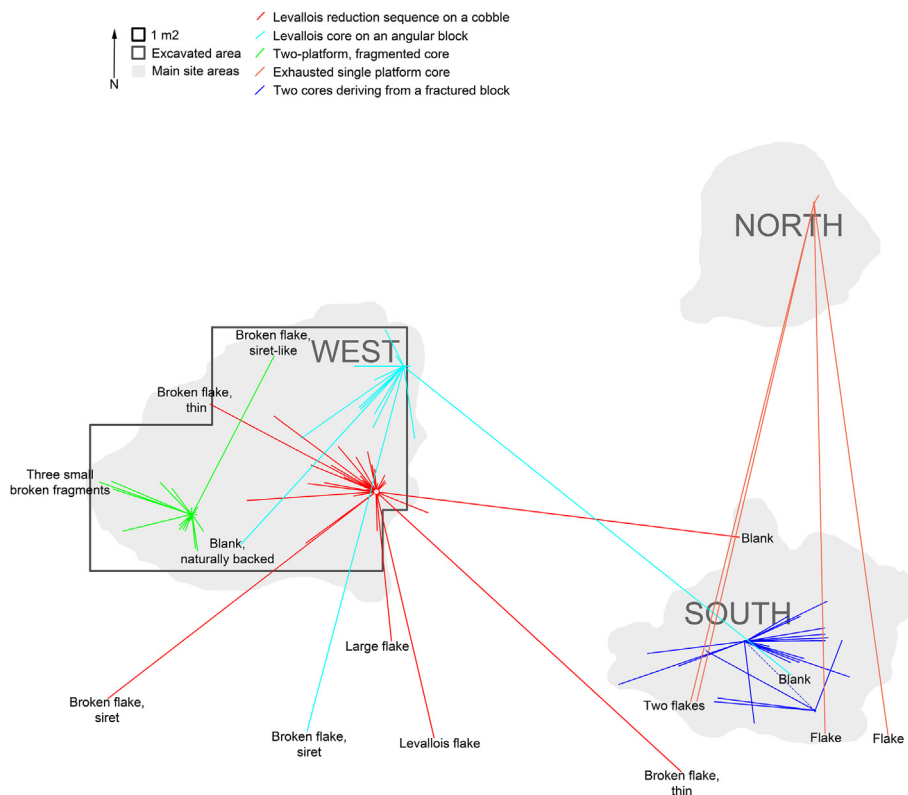


Fig. 10. Five refitted blocks from site MAK33, Ntwetwe Pan, also illustrated in Fig. 9 above. Lines radiate from the location of the core. In the case of the Levallois reduction sequence on a cobble (red), the core was not present on site and the knapping location is used as the focal point. The dashed line demarcates a natural fracture within a block. These examples are further described in the text. A blank here refers to a well-prepared (but not Levallois) flake of suitable size and thickness for tool production. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

core are the most widely separated, being found both in MAK33 North (core and final flake) and South (four flakes).

There are two clear examples of post-depositional movement by natural factors (Fig. 10). First, three small fragments from the **two-platform, fragmented core** that are of similar size and shape, have relocated to the salt rind zone, which has previously been argued to feature size sorting. Second, the distribution of the artefacts comprising the **two cores deriving from a fractured block** appears evenly if widely spread, with no distinct categories amongst the longest-distance refits. A likely hypothesis would be that this reflects generalized blurring of the exposed artefacts in this area through natural factors. The bidirectional plots of the **exhausted single platform core** reveal a pattern that is difficult to explain by natural displacement, as the two groups are located 45m apart with no intermediate occurrences. The disparate locations could be interpreted as either: i) the core and final flake relocated north, or ii) the four prior flakes moved south. These four flakes are knapping debris of non-predetermined shape, with a wide distribution similar to the other refitted block found in the same area. A plausible explanation could be that the core was moved from MAK33 South to MAK33 North for further knapping and abandoned there after one final removal.

Wind and water are also unlikely to be the drivers for the remaining ten long-distance refits. The artefacts vary in size and shape. Furthermore, they are restricted to the technological categories of blanks/large prepared flakes and certain broken flakes. These pieces originate in the three reconstructed sequences within MAK33 West (see Fig. 10), which overlies a silica/clay hardground that, as discussed in section 4.3.1, may inhibit post-depositional movement. The relocated blanks and prepared flakes ($N = 5$) are

of sizes and shapes suitable either for tool production or for hand-held use. The broken flakes also share morphological characteristics. Two are *silet* breaks, the result of a common hard hammer detachment error that produces a flake with a breakage plane with two c. 90° angles, similar to the working edges of burins (Inizan et al., 1999). A third displaced broken flake exhibits the same morphological edge characteristics but is the result of a snap break. The broken edges of these three flakes are of the same thickness, c. 3 mm. The final two displaced flake fragments refit to one another (separated by c. 50m), and while they also display a dual 90° angle break, this is only c. 1 mm thick. Previous usewear analyses of broken flakes with similar edge symmetry have documented their use as burins, for working organic material (Sørensen, 2017). The relocation of this many artefacts with shared, similar characteristics opens the possibility that these broken flakes have been selected for use. With regard to location, three of the ten displaced artefacts have moved internally within MAK33 West, four have moved to a broad zone south of MAK33 West, while the remainder have relocated to MAK33 South. The most plausible explanation appears to be a pattern of long-distance intentional movement of select artefacts from their knapping locations, likely for use or further modification.

4.3.3. MAK33: distribution of specific technological categories of artefacts

Based on the refitted groups described in section 4.3.2, the current artefact distribution at site MAK33 was formed by local knapping of silcrete blocks and select artefact movement, which has subsequently seen blurring due to wind and water. Animal trampling caused lesser, localized disturbance. If cultural factors are

indeed the chief cause of the current artefact distribution, we would expect to see i) parallel patterns when examining other aspects of the assemblage and ii) further connections between widely separated knapping areas on this expansive site. To test this hypothesis, location of retouched tools was mapped, as these artefacts are more likely to be selected for movement relative to cores and knapping debris. To examine possible links and differences between the main areas of the site, similar mapping was applied to artefacts pertaining to the two most characteristic point production strategies: Levallois reduction and bifacial working of natural blanks.

As discussed in [Staurset et al. \(2022\)](#), by far the most common retouched tools in the MSA of the Makgadikgadi basin are points. These can be further subdivided into unifacial ($N = 43$), bifacial ($N = 57$), and Levallois points with retouch ($N = 8$), with additional tool types limited to a variety of scrapers ($N = 18$). These retouched artefacts were found in all the three main areas where tool production took place (MAK33 West, North and South; see [Fig. 10](#)). A smaller number of individual tools were also recovered outside of these main areas, and these are overrepresented in the zones south of MAK33 West, north of MAK33 North and between MAK33 North and South. Further, the distribution of tool types is not random, with unifacial and Levallois points mostly located in MAK33 West, while bifacial points dominate elsewhere on site. Most of the scrapers are also located in MAK33 West, with occasional examples found in other sectors. While distributions have been blurred by post-depositional disturbance, it is unlikely that natural factors have caused tools to move from the main knapping areas to the adjacent zones. The most plausible explanation is that their current location is related to their discard during production or after use.

We further mapped out the distribution of artefacts pertaining to Levallois reduction (8 Levallois cores, 12 preferential flakes, 8 points with retouch) and bifacial working of natural blanks (2 points and 20 roughouts abandoned in production). We limited the latter category to raw material group K (see SOM1), a highly characteristic silcrete that forms in thin sheets and was only used to produce these points ([Staurset et al., 2022, Fig. 6](#)). As can be seen in [Fig. 12](#), Levallois artefacts are virtually restricted to area West, while the bifacial examples are found in all main areas. The former indicates that this part of the site was used for a specific manufacturing purpose. The corresponding distributions of unifacial points and scrapers in this area (see [Fig. 11](#)) is explained by the use of flakes from Levallois cores as blanks for these tools. The latter, wider distribution of the bifacial examples indicates that some reduction strategies were not restricted to certain geographic areas. Combined, these open possibilities to explore prehistoric spatial organisation in the context of skill levels and preferences of the MSA knappers. It is worth noting that while Levallois production was undertaken on a range of silcretes, it was still largely limited to one area of the site. The distinctive raw material group K was, however, worked in the same fashion across the site. This reinforces the links between the main areas of the site established by refits between them and increases the likelihood that they were contemporary.

5. Discussion and concluding remarks

This paper has presented an examination of the spatial patterning of five fully excavated MSA sites in Ntwetwe Pan, Makgadikgadi Basin, Botswana (see also [Staurset et al., 2022](#)). The lithic

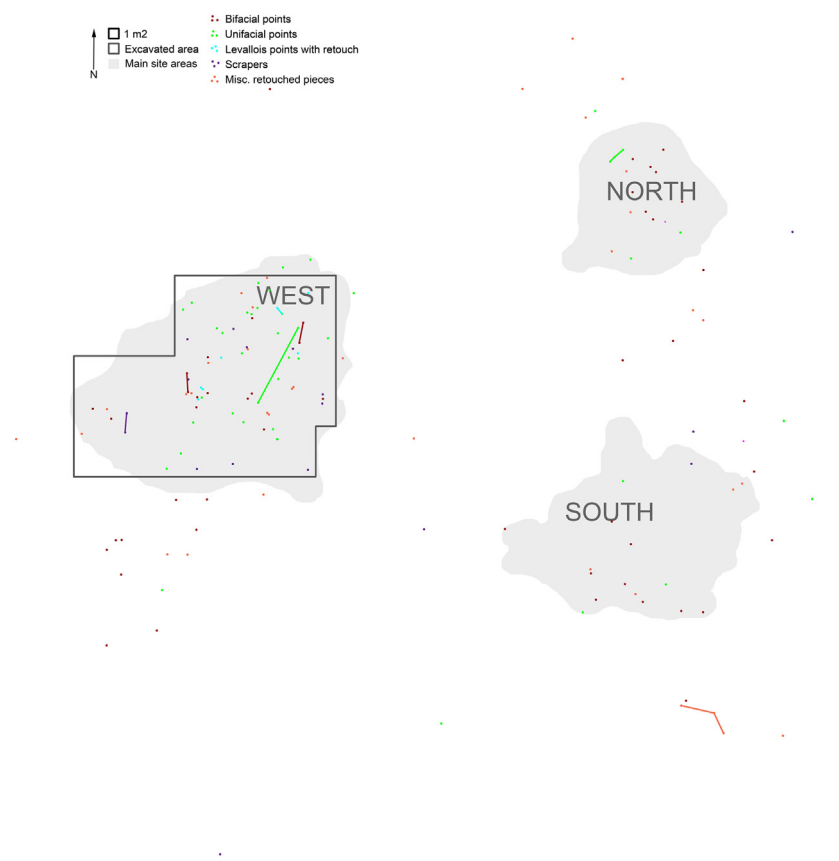


Fig. 11. Distribution of retouched tools at site MAK33, Ntwetwe Pan: bifacial points, unifacial points, Levallois points with retouch, scrapers, and miscellaneous retouched pieces. Overview includes broken tools and tools abandoned in final stages of production. Lines indicate mended artefacts.

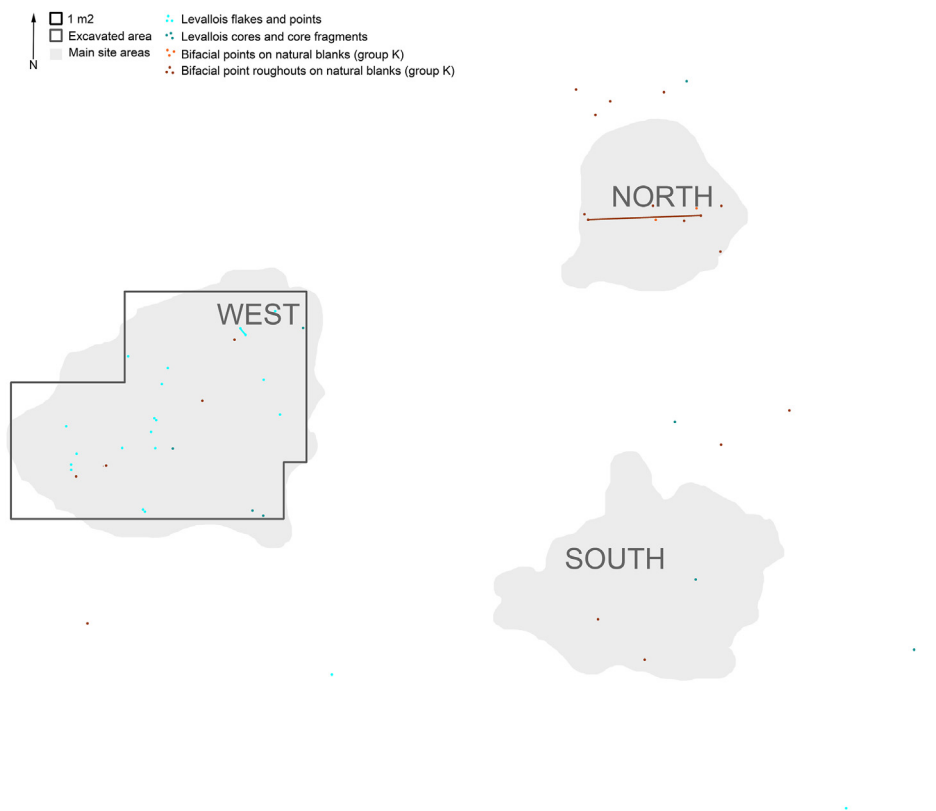


Fig. 12. Distribution of two distinct technological approaches at site MAK33, Ntwetwe Pan: Levallois type finds (Levallois cores, preferential flakes, Levallois points with retouch) and points/roughouts made on natural blanks in raw material group K. Overview includes broken tools. Lines indicate mended artefacts.

assemblages were examined using a *chaîne opératoire* approach with an emphasis on refitting and aimed to understand natural and cultural factors contributing to the artefact spread on these exposed open-air sites. The distribution of archaeological material at the excavated sites was found to have been affected by a combination of cultural and natural factors, indicating differential local environmental factors and, likely, some variety in prehistoric usage.

The two smaller sites, MAK2 and MAK15, offered no apparent cultural spatial patterns, and the distribution of the limited number of artefacts recovered appeared blurred, likely due to localised movement by water. At MAK15 the distribution may have been particularly affected by flood waters acting against the nearby dune edge. The assemblages at both sites comprise evidence of several late-stage, disjointed *chaînes opératoires*, suggesting they were utilized for brief re-tooling episodes.

The two medium-sized sites, MAK14K and MAK14O, yielded distinctly different spatial patterning. At MAK14K the artefact spread again appears to have been influenced by a dune, while a cluster of retouched tools and cores was still located adjacent to a hardened clay section of the pan floor. This blurred cluster may reflect the discard of exhausted or otherwise undesirable retouched pieces that were not considered worth carrying further. Conversely, artefact mapping of site MAK14O displayed no indications of cultural patterns. Here, the lithic distribution was blurred to a much greater extent, consistent with fanning spread away from nearby clay and dune formations. Although the site appeared a good candidate for spatial behavioural mapping during excavation, the subsequent analysis failed to show clustering based on raw material, technological stage, or movement of refitted pieces. However, both these medium sites showed evidence of more extensive and multi-stage lithic production when compared to the smaller sites, indicating that a wider range of activities had taken place.

The largest excavated site, MAK33, yielded by far the most information. Here, ca. 21% of the assemblage was refitted, which made it possible to map out *chaîne opératoire* stages and artefact movement across the site. The distribution of the overall assemblage indicated three main site areas: MAK33 West, North and South. To illustrate the connections between these areas, artefacts pertaining to five larger refitted blocks were mapped out, confirming that these were anchored in these geographic areas of the site. Artefacts from these refitted sequences that were recovered away from what appeared to be the original working areas tended to fall into two distinct technological categories: i) prepared flakes/blanks; and ii) flakes with a distinct break, similar to a *siret* break. This indicates that original working areas at this site can still be identified, and that select artefacts were moved from their place of manufacture to other areas on-site, plausibly for further modification or direct use. Mapping of distinct MSA point types reinforces the cultural patterning: Levallois points and production sequences dominate in area MAK33 West, while bifacial production and tools are dominant in areas North and South. As areas MAK33 West, North and South are linked by refits, and all include the production of a distinct tool type (bifacial points made on natural blanks on a specific type of silcrete) they are highly likely to be contemporaneous. MAK33 however also displays indications of natural disturbance, including water action on smaller artefacts and limited animal trampling. The artefact distributions in areas MAK33 North and South appears more blurred than that of MAK33 West, probably caused by the latter's correlation with a slightly elevated local silica/clay hardground area. Combined, these results indicate that planned and specialized production took place on this site, with different areas of the site dedicated to different aspects of point production in a variety of silcretes. This production, combined with the many discarded points, suggests that a large number of the

tools MSA people arrived with were substituted for new ones. This could indicate the site was used in response to a specific occasion or task that required new tools, or in anticipation of moving into areas where raw materials were scarcer.

The results from the four sites presented here indicate that i) refitting combined with total excavation provides a methodological framework within which post-depositional disturbance on open-air sites can be assessed; ii) cultural distribution patterns of lithic material can be preserved even in exposed environment such as Ntswetwe Pan, although with large local variations; and iii) open-air sites may preserve other spatial behaviours than those recognized in cave/shelter sites. This final point rests on the analysis of the artefact distribution at site MAK33, which makes it possible to draw some further inferences on MSA behaviour. First, the total artefact spread encompasses c. 75×75 m but appears contemporaneous and the result of a single visit. This is much larger than most excavated MSA sites, but not unusual in the context of surveyed sites in Ntswetwe Pan (see also Coulson et al., 2022). This indicates that MSA people have adapted their site organization to conditions imposed by local geography, with contrasting results found in caves and open-air sites. Second, the non-random lithic distribution indicates that it is possible to reconstruct MSA working areas. The distribution of refitted sequences and lithic debris across the site imply that, while artefact types such as bifacial points were produced everywhere (or by everyone), certain production approaches such as Levallois was limited to certain areas (or certain knappers).

This raises a number of questions regarding the potential and practice of MSA peoples, including how they organized their activities (e.g., specialized production, knapping expertise, learning, interaction of craftspeople, activity planning) and how these could be recognized in the archaeological record. Future experimental research could provide a major contribution to understanding these patterns, for example through mapping the movement of exposed lithic material on pan floors over several seasons. More importantly, experimental production of silcrete MSA tools and mapping of resultant debris dispersal during a variety of local conditions and levels of knapping expertise could provide an essential comparative basis to the archaeological distributions. Such experiments could, for example, examine the difference of lithic spread within an enclosed area such as a cave and an open-air location, establish ranges of flake movement upon detachment in MSA production, and how the inclusion of multiple knappers and/or work areas interact.

Results from the excavated sites presented here emphasize the necessity to assess post-depositional disturbance before interpretations are made. A pristine, undisturbed MSA occupation is unlikely to ever be excavated, but developments in sedimentary and lithic analysis in many cases make it possible to discern natural from cultural artefact movement. In the context of the five sites discussed here, the choice of full excavation and extensive refitting was essential. The recent excavations in Ntswetwe Pan (Burrough et al., 2022; Nash et al., 2022; Staurset et al., 2022; Thomas et al., 2022) aimed at investigating human-landscape interaction in the Makgadikgadi Basin, and whether the scarcity of MSA sites in the interior subcontinent stemmed from limited MSA occupations, limited research, or a perception that a lack of cave locales mean a lack of sites that can yield significant archaeological information. The documentation of a large number of Middle Kalahari sites by Coulson et al. (2022) indicates that MSA occupation was widespread and is under-researched. The results presented in this paper further document that exposed, open-air sites can document MSA spatial organization not previously documented in cave and shelter sites. Combined, these emphasize the importance of the less documented landscapes of the African interior as a crucial source of Stone Age behavioural records.

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: Principal 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.

Acknowledgements

These investigations were carried out under research permit EWT 8/36/4 XXXV (9), issued April 22, 2016 by the Botswana Ministry of Environment, Wildlife and Tourism (ref EWT 8/36/4 XXXV (52)), extended on June 29, 2018 by the Botswana Ministry of Environment, Natural Resources, Conservation and Tourism (ref ENT 8/36/4 XXXXII (43)).

This interdisciplinary project was funded by the Leverhulme Trust. Additional funding and aid were gratefully received from the University of Oxford, the University of Brighton, the University of Botswana, the University of Oslo and Norsk Arkeologisk Selskap. We also wish to acknowledge the continued support of the National Museum of Botswana for laboratory space, the loan of equipment and storage and especially to the Head of Archaeology, Phillip Segadika, for his continued support and advice. Our appreciation goes to Ralph Bousfield and Uncharted Africa for generous advice, access to field research station, facilities and storage, and field assistance and to the owners and staff of Gweta Lodge for field assistance and sharing of local knowledge. Our thanks to Eric Walker for his continued assistance. We would like to thank the two anonymous reviewers whose constructive and helpful suggestions improved this manuscript.

Most of all, we wish to express our gratitude and appreciation to University of Botswana students Oratile Ramore, Cathrine Legabe, Jane Masisi, Topo Mpho Chengeta, Casper Lekgetho and Agang Motlaleng for their diligence and contributions to archaeology through their fieldwork in Ntswetwe Pan.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.quascirev.2022.107824>.

References

- Anderson, L., Lejay, M., Brugal, J.-P., Costamagno, S., Heckel, C., de Araujo Igrreja, M., Pradeau, J.V., Salomon, H., Sellami, F., Théry-Parisot, I., Barshay-Szmidt, C., Mensan, R., Bon, F., 2018. Insights into Aurignacian daily life and camp organization: the open-air site of Régismont-le-Haut. *Quat. Int.* 498, 69–98.
- Araujo, A.G.M., 2013. Bioturbation and the upward movement of sediment particles and archaeological materials: Comments on Bueno et al. *J. Archaeol. Sci.* 40 (4), 2124–2127.
- Aura, J.E., Jordá, J.F., Montes, L., Utrilla, P., 2011. Human responses to younger Dryas in the Ebro valley and Mediterranean watershed (Eastern Spain). *Quat. Int.* 242 (2), 348–359.
- Bailey, G., 2007. Time perspectives, palimpsests and the archaeology of time.

- J. Anthropol. Archaeol. 26 (2), 198–223.
- Bailey, G., Galanidou, N., 2009. Caves, palimpsests and dwelling spaces: examples from the Upper Palaeolithic of south-east Europe. *World Archaeol.* 41 (2), 215–241.
- Bamforth, D.B., 1990. Settlement, raw-material, and lithic procurement in the central Mojave Desert. *J. Anthropol. Archaeol.* 9 (1), 70–104.
- Bar-Yosef, O., Van Peer, P., 2009. *La chaîne opératoire* approach in Middle Palaeolithic archaeology. *Curr. Anthropol.* 50 (1), 103–131.
- Barton, R.N.E., Bergman, C.A., 1982. Hunters at Hengistbury: some evidence from experimental archaeology. *World Archaeol.* 14, 237–248.
- Bartram, L.E., Kroll, E.M., Bunn, H.T., 1991. Variability in camp structure and bone food refuse patterning at Kua San hunter-gatherer camps. In: Kroll, E.M., Price, T.D. (Eds.), *The Interpretation of Archaeological Spatial Patterning*. Plenum Press, New York, pp. 77–148.
- Bergman, C.A., Roberts, M.B., Colcutt, S., Barlow, P., 1990. Refitting and spatial analysis of artefacts from Quarry 2 at the Middle Pleistocene Acheulean site of Boxgrove, West Sussex, England. In: Czesla, E., Eickhoff, S., Arts, N., Winter, D. (Eds.), *The Big Puzzle. International Symposium on Refitting Stone Artefacts, Studies in Modern Archaeology*, vol. 1. HOLOS, Bonn, pp. 265–281.
- Boëda, E., Pelegrin, J., 1985. Approche expérimentale des amas de Marsangy. In: *Les amas lithiques de la zone N19 du gisement Magdalénien de Marsangy: approche méthodologique par l'expérimentation*, vol. 1. Archéologie Expérimentale, pp. 19–36.
- Brooks, A.S., 1984. San land-use patterns, past and present: implications for Southern African Prehistory. In: Hall, M., Avery, G., Avery, D.M., Wilson, M.L., Humphreys, A.J.B. (Eds.), *Frontiers: Southern African Archaeology Today*, Cambridge Monographs in African Archaeology, vol. 10. British Archaeological Reports, Cambridge, pp. 40–52.
- Brooks, A.S., Yellen, J.E., 1987. The preservation of activity areas in the archaeological record: Ethnoarchaeological and archaeological work in northwest Ngamiland, Botswana. In: Kent, S. (Ed.), *Method and Theory for Activity Area Research: An Ethnoarchaeological Approach*. Columbia University press, New York, pp. 63–106.
- Brooks, A.S., Nevell, L., Yellen, J.E., Hartman, G., 2006. Projectile technologies of the African MSA: implications for modern human origins. In: Hovers, E., Kuhn, S.L. (Eds.), *Transitions before the Transition. Evolution and Stability in the Middle Paleolithic and Middle Stone Age*, Interdisciplinary Contributions to Archaeology. Springer, pp. 233–256.
- Burroni, D., Donahue, R.E., Pollard, A.M., Mussi, M., 2002. The surface alteration features of flint artefacts as a record of environmental processes. *J. Archaeol. Sci.* 29 (11), 1277–1287.
- Burrough, S.L., Thomas, D.S.G., Bailey, R.M., 2009. Mega-lake in the Kalahari: a late Pleistocene record of the palaeolake Makgadikgadi system. *Quat. Sci. Rev.* 28, 1392–1411.
- Burrough, S.L., Thomas, D.S.G., Allin, J.A., Coulson, S., Mothulatshipi, S., Nash, D.J., Staurset, S., 2022. Lessons from a lakebed: unpicking hydrological change and early human landscape use in the Makgadikgadi basin, Botswana. *Quat. Sci. Rev.* 291, 107662.
- Bustos-Pérez, G., Díaz, S., Baena, J., 2019. An experimental approach to degrees of rounding among lithic artifacts. *J. Archaeol. Method Theor* 26 (4), 1243–1275.
- Cahen, Daniel, 1987. Refitting stone artifacts: why bother? In: Sieveking, G.d.G., Newcomer, M.H. (Eds.), *The Human Uses of Flint and Chert. Proceedings of the Fourth International Flint Symposium held at Brighton Polytechnic 10–15 April 1983*. Cambridge University Press, Cambridge, pp. 1–10.
- Cahen, D., Moeyersons, J., 1977. Subsurface movements of stone artefacts and their implications for the prehistory of Central Africa. *Nature* 266 (5605), 812–815.
- Clark, Amy E., 2017. From activity areas to occupational histories: new methods to document the formation of spatial structure in hunter-gatherer sites. *J. Archaeol. Method Theor* 24 (4), 1300–1325.
- Clark, Amy E., 2019. Using spatial context to identify lithic selection behaviors. *J. Archaeol. Sci.: Reports* 24, 1014–1022.
- Close, Angela E., 2000. Reconstructing movement in prehistory. *J. Archaeol. Method Theor* 7 (1), 49–77.
- Cooke, H.J., 1980. Landform Evolution in the context of climatic change and Neotectonism in the Middle Kalahari of North-Central Botswana. *Trans. Inst. Br. Geogr.* 5 (1), 80–99.
- Coulson, S., Andreasen, C., 2020. Uncovering their tracks: Intra-site behaviour at a Paleo-Inuit multiple dwelling site. *J. Anthropol. Archaeol.* 58, 101169.
- Coulson, S., Staurset, S., Walker, N., 2011. Ritualized behavior in the Middle Stone Age: evidence from Rhino Cave, Tsodilo Hills, Botswana. *PaleoAnthropology* 2011, 18–61.
- Coulson, S.D., Staurset, S., Mothulatshipi, S., Burrough, S.L., Nash, D.J., Thomas, D.S.G., 2022. Thriving in the Thirstland: New Stone Age sites from the Middle Kalahari, Botswana. *Quat. Sci. Rev.* 297, 107662.
- de la Peña, P., Wadley, L., 2014. New knapping methods in the Howiesons Poort at Sibudu (KwaZulu-Natal, South Africa). *Quat. Int.* 350, 26–42.
- de la Torre, I., Vanwezer, N., Benito-Calvo, A., Proffitt, T., Mora, R., 2019. Spatial and orientation patterns of experimental stone tool refits. *Archaeol. Anthropol. Sci.* 11, 4569–4584.
- Deschamps, M., Zilhão, J., 2018. Assessing site formation and assemblage integrity through stone tool refitting at Gruta da Oliveira (Almonda karst system, Torres Novas, Portugal): a Middle Paleolithic case study. *PLoS One* 13 (2), e0192423.
- Dibble, H.L., Chase, P.G., McPherron, S.P., Tuffreau, A., 1997. Testing the reality of a 'living floor' with archaeological data. *Am. Antiq.* 62 (4), 629–651.
- Dietl, H., Kandel, A.W., Conard, N.J., 2005. Middle Stone Age settlement and land use at the open-air sites of Geelbek and Anyskop, South Africa. *J. Afr. Archaeol.* 3 (2), 231–242.
- Eckardt, F.D., Bryant, R.G., McCulloch, G.P., Spiro, B.F., Wood, W.W., 2008. The hydrochemistry of a semi-arid pan basin case study: Sua Pan, Makgadikgadi, Botswana. *Appl. Geochem.* 23, 1563–1580.
- Eren, M.I., Durant, A., Neudorf, C., Haslam, M., Shipton, C., Bora, J., Korisettar, R., Petraglia, M., 2010. Experimental examination of animal trampling effects on artifact movement in dry and water saturated substrates: a test case from South India. *J. Archaeol. Sci.* 37 (12), 3010–3021.
- Forssman, T., Pargeter, J., 2014. Assessing surface movement at Stone Age open-air sites: first impressions from a pilot experiment in northeastern Botswana. *South. Afr. Humanit.* 26, 157–176.
- Fuchs, M., Kandel, A.W., Conard, N.J., Walker, S.J., Felix-Henningsen, P., 2008. Geoarchaeological and chronostratigraphical investigations of open-air sites in the Geelbek Dunes, South Africa. *Geoarchaeology* 23 (4), 425–449.
- Gifford, D.P., Behrensmeier, A.K., 1977. Observed formation and burial of a recent human occupation site in Kenya. *Q. Res.* 8 (3), 245–266.
- Gifford-Gonzalez, D.P., Damrosch, D.B., Damrosch, D.R., Pryor, J., Thunen, R.L., 1985. The third dimension in site structure: an experiment in trampling and vertical dispersal. *Am. Antiq.* 50 (4), 803–818.
- Haddon, I.G., McCarthy, T.S., 2005. The Mesozoic-Cenozoic interior sag basins of central Africa: the late-Cretaceous-Cenozoic Kalahari and Okavango basins. *J. Afr. Earth Sci.* 43 (1–3), 316–333.
- Helgren, D.M., Brooks, A.S., 1983. Geoarchaeology at Gi, a Middle Stone Age and Later Stone Age site in the northwest Kalahari. *J. Archaeol. Sci.* 10, 181–197.
- Higham, T., Brock, F., Ramsey, C., Davies, W., Wood, R., Basell, L., 2011. Chronology of the site of Grotte du Renne, Arcy-sur-Cure, France: implications for Neanderthal symbolic behaviour. *Before Farming* 2011 (2), 1–9.
- Hofman, J.L., 1981. The refitting of chipped-stone artifacts as an analytical and interpretive tool. *Curr. Anthropol.* 22 (6), 691–693.
- Hofman, J.L., 1986. Vertical movement of artifacts in alluvial and stratified deposits. *Curr. Anthropol.* 27 (2), 163–171.
- Hunt, C.O., Gilbertson, D.D., Hill, E.A., Simpson, D., 2015. Sedimentation, re-sedimentation and chronologies in archaeologically-important caves: problems and prospects. *J. Archaeol. Sci.* 56, 109–116.
- Inizan, M.-L., Reduron-Ballinger, M., Roche, H., Tixier, J., 1999. Technology and Terminology of Knapped Stone. *J. Félét-Augustins*, transl. Nanterre: CREP.
- Kandel, A.W., Conard, N.J., 2012. Settlement patterns during the Earlier and Middle Stone Age around Langebaan Lagoon, Western Cape (South Africa). *Quat. Int.* 270, 15–29.
- Karlin, C., Julien, M., 2019. An autumn at Pincevent (Seine-et-Marne, France): refitting for an ethnographic approach of a Magdalenian settlement. *Archaeological and Anthropological Sciences* 11 (9), 4437–4465.
- Kelly, R.L., 1988. The three sides of a biface. *Am. Antiq.* 53 (4), 717–734.
- Knight, J., Stratford, D., 2020. Investigating lithic scatters in arid environments: the Early and Middle Stone Age in Namibia. *Proc. Geologists' Assoc.* 131 (6), 778–783.
- Kroll, E.M., Price, T.D. (Eds.), 1991. *The Interpretation of Archaeological Spatial Patterning*. Springer Science & Business Media.
- Larson, M.L., Ingbar, E.E., 1992. Perspectives on refitting: critique and a complementary approach. In: Hofman, J.L., Enloe, J.G. (Eds.), *Piecing Together the Past: Applications of Refitting Studies in Archaeology*, vol. 578. BAR International Series, pp. 151–162.
- Larson, M.L., Kornfeld, M., 1997. Chipped stone nodules: theory, method and examples. *Lithic Technol.* 22 (1), 4–18.
- Lewarch, D.E., O'Brien, M.J., 1981. The expanding role of surface assemblages in archaeological research. *Adv. Archaeol. Method Theor.* 4, 297–342.
- López-Ortega, Esther, Rodríguez-Álvarez, X.P., Ollé, A., Lozano, S., 2019. Lithic refits as a tool to reinforce postdepositional analysis. *Archaeological and Anthropological Sciences* 11 (9), 4555–4568.
- Lyman, R.L., 2008. (Zoo)Archaeological refitting: a consideration of methods and analytical search radius. *J. Anthropol. Res.* 64 (2), 229–248.
- Marwick, B., Hayes, E., Clarkson, C., Fullagar, R., 2017. Movement of lithics by trampling: an experiment in the Madjedbebe sediments, northern Australia. *J. Archaeol. Sci.* 79, 73–85.
- McBrearty, S., 1990. Consider the humble termite: Termites as agents of post-depositional disturbance at African archaeological sites. *J. Archaeol. Sci.* 17 (2), 111–143.
- McBrearty, S., Bishop, L., Plummer, T., Dewar, R., Conard, N., 1998. Tools underfoot: human trampling as an agent of lithic artifact edge modification. *Am. Antiq.* 63 (1), 108–129.
- McCulloch, G.P., Irvine, K., Eckardt, F.D., Bryant, R.G., 2008. Hydrochemical fluctuations and crustacean community composition in an ephemeral saline lake (Sua Pan, Makgadikgadi Botswana). *Hydrobiologia* 596, 31–46.
- Moeyersons, J., 1978. The behaviour of stones and stone implements, buried in consolidating and creeping Kalahari sands. *Earth Surf. Process.* 3 (2), 115–128.
- Mourre, V., Villa, P., Henshilwood, C., 2010. Early use of pressure flaking on lithic artifacts at Blombos Cave, South Africa. *Science* 330, 659–662.
- Nash, D.J., Shaw, P.A., 1998. Silica and carbonate relationships in silcrete-calcrete intergrade duricrusts from the Kalahari of Botswana and Namibia. *J. Afr. Earth Sci.* 27, 11–25.
- Nash, D.J., Ulyott, J.S., 2007. Silcrete. In: Nash, D.J., McLaren, S.J. (Eds.), *Geochemical Sediments and Landscapes*. Blackwell, Oxford, pp. 95–143.
- Nash, D.J., McLaren, S.J., Webb, J.A., 2004. Petrology, geochemistry and environmental significance of silcrete-calcrete intergrade duricrusts at Kang Pan and

- Tswaane, Central Kalahari, Botswana. *Earth Surf. Process. Landforms* 29, 1559–1586.
- Nash, D.J., Ciborowski, T.J.R., Coulson, S.D., Staurset, S., Burrough, S.L., Mothulatshipi, S., Thomas, D.S.G., 2022. Mapping Middle Stone Age human mobility in the Makgadikgadi Pans (Botswana), through multi-site geochemical provenancing of silcrete artefacts. *Quat. Sci. Rev.* 297, 107811.
- Newcomer, M.H., Sieveking, G. de G., 1980. Experimental flake scatter-patterns: a new interpretative technique. *J. Field Archaeol.* 7 (3), 345–352.
- Nield, J.M., Bryant, R.G., Wiggs, G.F., King, J., Thomas, D.S.G., Eckardt, F.D., Washington, R., 2015. The dynamism of salt crust patterns on playas. *Geology* 43 (1), 31–34.
- Nielsen, A.E., 1991. Trampling the archaeological record: an experimental study. *Am. Antiq.* 56 (3), 483–503.
- Oestmo, S., Schoville, B.J., Wilkins, J., Marean, C.W., 2014. A Middle Stone Age Palaeoscape near the Pinnacle Point Caves, Vleesbaai, South Africa. *Quat. Int.* 350, 147–168.
- Olive, M., 2004. À propos du gisement magdalénien d'Etiolles (Essonne): réflexion sur la fonction d'un site paléolithique. *Bull. Soc. Prehist. Fr.* 101, 797–813.
- Pargeter, J., Bradfield, J., 2012. The effects of Class I and II sized bovids on macrofracture formation and tool displacement: results of a trampling experiment in a southern African Stone Age context. *J. Field Archaeol.* 37 (3), 238–251.
- Phillipps, R.S., Holdaway, S.J., 2016. Estimating core number in assemblages: core movement and mobility during the Holocene of the Fayum, Egypt. *J. Archaeol. Method Theor* 23 (2), 520–540.
- Reynard, J.P., Henshilwood, C.S., 2018. Using trampling modification to infer occupational intensity during the Still Bay at Blombos Cave, Southern Cape, South Africa. *Afr. Archaeol. Rev.* 35 (1), 1–19.
- Ringrose, S., Cassidy, L., Diskin, S., Coetzee, S., Matheson, W., Mackay, A.W., Harris, C., 2014. Diagenetic transformations and silcrete-calcrete intergrade duricrust formation in palaeo-estuary sediments. *Earth Surf. Process. Landforms* 39, 1167–1187.
- Roebroeks, J.W.M., Kolen, J., Poecke, M.V., Van Gijn, A.L., 1997. Site J: an early Weichselian (Middle Palaeolithic) flint scatter at Maastricht-Belvedere, The Netherlands. *Paléo* 9, 143–172.
- Romagnoli, F., Vaquero, M., 2019. The challenges of applying refitting analysis in the Palaeolithic archaeology of the twenty-first century: an actualised overview and future perspectives. *Archaeological and Anthropological Sciences* 11 (9), 4387–4396.
- Scerri, E.M., Gravina, B., Blinkhorn, J., Delagnes, A., 2016. Can lithic attribute analyses identify discrete reduction trajectories? A quantitative study using refitted lithic sets. *J. Archaeol. Method Theor* 23 (2), 669–691.
- Schiffer, M.B., 1983. Toward the identification of formation processes. *Am. Antiq.* 48 (4), 675–706.
- Schurmans, U.A., 2007. Refitting in the Old and New Worlds. In: Schurmans, U.A., De Bie, M. (Eds.), *Fitting Rocks. Lithic Refitting Examined*, British Archaeological Reports International Series, vol. 1596. Archaeopress, Oxford, pp. 7–23.
- Shackley, M.L., 1974. Stream abrasion of flint implements. *Nature* 248 (5448), 501–502.
- Shaw, P.A., Cooke, H.J., 1986. Geomorphic evidence for the late Quaternary palaeoclimates of the Middle Kalahari of northern Botswana. *Catena* 13, 349–359.
- Shaw, M., Ames, C.J., Phillips, N., Chambers, S., Dosseto, A., Matthew, D., Goble, R., Jacobs, Z., Jones, B., Lin, S., Low, M., McNeil, J.-L., Nasoordeen, S., O'Driscoll, C.A., Saktura, R.B., Sumner, T.A., Watson, S., Will, M., MacKay, A., 2019. The Doring River Archaeology Project: approaching the evolution of human land use patterns in the Western Cape, South Africa. *PaleoAnthropology* 2019, 400–422.
- Sørensen, M., 2017. How to classify lithic artefacts - if at all: the case of the burin. Sørensen, M., Pedersen, K.B. (Eds.), *Problems in Palaeolithic and Mesolithic Research*. Københavns Universitet, Humanistisk Fakultet, Denmark, pp. 207–225.
- Soressi, M., Geneste, J.-M., 2011. The history and efficacy of the *chaîne opératoire* approach to lithic analysis: Studying techniques to reveal past societies in an evolutionary perspective. *PaleoAnthropology* 2011, 334–350.
- Staurset, S., Coulson, S., 2014. Sub-surface movement of stone artefacts at White Paintings Shelter, Tsodilo Hills, Botswana: implications for the Middle Stone Age chronology of central southern Africa. *J. Hum. Evol.* 75, 153–165.
- Staurset, S., Coulson, S.D., Mothulatshipi, S., Burrough, S.L., Nash, D.J., Thomas, D.S.G., 2022. Making points: the Middle Stone Age lithic industry of the Makgadikgadi basin, Botswana. *Quat. Sci. Rev.* In press.
- Stern, S., 1994. The implications of time-averaging for reconstructing the land-use patterns of early tool-using hominids. *J. Hum. Evol.* 27 (1–3), 89–105.
- Stewart, B.A., Dewar, G., Morley, M., Inglis, R., Wheeler, M., Jacobs, Z., Roberts, R.G., 2012. Afromontane foragers of the late Pleistocene: site formation, chronology and occupational pulsing at Melikane Rockshelter, Lesotho. *Quat. Int.* 270, 40–60.
- Thomas, D.S.G., 1988. The nature and depositional setting of arid and semi-arid Kalahari sediments, southern Africa. *J. Arid Environ.* 14, 17–26.
- Thomas, D.S.G., Burrough, S.L., Coulson, S.D., Nash, D.J., Mothulatshipi, S., Staurset, S., 2022. Lacustrine geoarchaeology in the central Kalahari: implications for Middle Stone Age, behaviour and adaptation in dryland conditions. *Quat. Sci. Rev.* 297, 107826.
- Tribolo, C., Mercier, N., Rasse, M., Soriano, S., Huysecom, E., 2010. Kobo 1 and l'Abri aux Vaches (Mali, West Africa): two case studies for the optical dating of bioturbated sediments. *Quat. Geochronol.* 5 (2–3), 317–323.
- Vaquero, M., Fernández-Laso, M.C., Chacón, M.G., Romagnoli, F., Rosell, J., Sañudo, P., 2017. Moving things: Comparing lithic and bone refits from a Middle Paleolithic site. *J. Anthropol. Archaeol.* 48, 262–280.
- Vaquero, M., Romagnoli, F., Bargalló, A., Chacón, M.G., Gómez de Soler, B., Picin, A., Carbonell, E., 2019. Lithic refitting and intrasite artifact transport: a view from the Middle Paleolithic. *Archaeological and Anthropological Sciences* 11 (9), 4491–4513.
- Vickery, K.J., Eckardt, F.D., Bryant, R.G., 2013. A sub-basin scale dust plume source frequency inventory for southern Africa, 2005–2008. *Geophysical Research Letters* 40, 5274–5279.
- Villa, P., 1982. Conjoinable pieces and site formation processes. *Am. Antiq.* 47 (2), 276–290.
- Villa, P., Boscato, P., Ranaldo, F., Ronchitelli, A., 2009. Stone tools for the hunt: points with impact scars from a Middle Pleistocene site in southern Italy. *J. Archaeol. Sci.* 36, 850–859.
- Villa, P., Courtin, J., 1983. The interpretation of stratified sites: a view from underground. *J. Archaeol. Sci.* 10 (3), 267–281.
- Webb, J.A., Nash, D., 2020. Reassessing southern African silcrete geochemistry: implications for silcrete origin and sourcing of silcrete artefacts. *Earth Surf. Process. Landforms* 45, 3396–3413.
- Wilkins, J., Chazan, M., 2012. Blade production 500 thousand years ago at Kathu Pan 1, South Africa: support for a multiple origins hypothesis for early Middle Pleistocene blade technologies. *J. Archaeol. Sci.* 39 (6), 1883–1900.
- Wilmsen, E.N., 1978. Prehistoric and historic antecedents of a contemporary Ngamiland community. *Botsw. Notes Rec.* 10, 5–18.
- Yellen, J.E., 1977. *Archaeological approaches to the present: Models for reconstructing the past*. Academic Press, New York.
- Yellen, J.E., 1990. The Transformation of the Kalahari !Kung. *Scientific American*, pp. 96–105.
- Yellen, J.E., Brooks, A.S., 1989. The Late Stone Age archaeology of the !Kangwa and/Xai/Xai Valleys, Ngamiland. *Botsw. Notes Rec.* 20, 5–27.
- Yellen, J.E., Brooks, A., Helgren, D., Tappen, M., Ambrose, S., Bonnefille, R., Feathers, J., Goodfriend, G., Ludwig, K., Renne, P., Stewart, K., 2005. The archaeology of Aduma Middle Stone Age sites in the Awash Valley, Ethiopia. *PaleoAnthropology* 2005, 25–100.