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Lacustrine geoarchaeology in the central Kalahari: Implications for Middle Stone Age behaviour and adaptation in dryland conditions

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A R T I C L E I N F O

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A B S T R A C T

The Middle Stone Age (MSA) was a time of great human adaptation and innovation. In southern Africa, coastal locations have been viewed as key places for the development of human resource use and behaviour, with the dryness of the continental interior after c.130 ka regarded as both an obstacle to occupation and a limit on behaviour. Newly excavated MSA sites on the floor of the now-dry palaeolake Makgadikgadi basin, central Botswana, along with accompanying environmental data, have provided a significant opportunity to reassess the nature of MSA adaptation to, and behaviour under, dry conditions. Excavated sites dated to 80–72 ka and post 57 ka reveal purposeful early human use of an extensive 60,000 km^2 lacustrine basin during dry, as opposed to lake-high, phases, as well as highlighting movement strategies for tool-making resource procurement. Findings have significant implications for theories of early human mobility and innovation, as well as for understanding the drivers, constraints and opportunities for the use of drylands. The deliberate selective movement of lithic raw materials within the basin for artefact manufacture evidences thoughtful adaptation to dry conditions within the lake basin. This research shows that open-air sites in the Kalahari drylands of central southern Africa can make important contributions to debates surrounding the development of human-environment relationships during the MSA, as well as challenging narratives of a hostile and largely empty landscape.

1. Introduction

Knowledge of the evolving relationship between ancestral hominins, early humans and the natural environment, and the development of theories of adaptation, is reliant upon robust archaeological and palaeo-landscape data that have strong age control and wide geographical coverage. Given *Homo sapiens*' African origin, popular debates on the nature and timing of human dispersal across the globe are predicated upon an enriched knowledge of how behavioural patterns and coping strategies first evolved in Africa – principally since c.300,000 kyr during the Middle Stone Age (MSA: c.280 ka-45 ka: Schoville et al., 2022) – where this occurred. Much of the key research that informs these debates has developed from the rich coeval environmental and fossil records of eastern Africa (Potts et al., 2018), and from coastal locations in southern Africa where access to rich marine resources is thought to have contributed to enhanced cognitive behaviour (Marean, 2016; Will et al., 2019).

Water availability inevitably plays a key role in narratives of *Homo sapien* dynamics within the African environment. These include debates around landscape niche occupation (Barham, 2000), access to resources (Basell, 2008), resource procurement (Nash et al., 2016) and other dimensions of mobility. This is no better evidenced than in debates regarding the spread of early humans within and from Africa. The moisture deficient drylands of today's Sahel-Sahara belt, and the neighbouring Levant and Arabia, are regions that would have had to be negotiated, or avoided (Forster and Matsumura, 2005), as dispersal to Asia, Europe and beyond occurred. A series of factors have been proposed in

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explanations for changes in the range of human during the MSA, and for migration from Africa from 70 ka or earlier. These include: (i) wet 'pull' factors, including a green Sahara providing new environmental opportunities (Drake et al., 2011); (ii) wet 'push' factors, including the provision of environmental conditions favouring population expansion within eastern Africa (Scholz et al., 2007); and (iii) dry 'push' factors associated with environmental deterioration in source regions (Tierney et al., 2017).

Central southern Africa has for the most part not featured significantly in the growth of ideas about human evolution, and dispersal in recent decades, other than being regarded as a virtually empty space (Wadley, 2015; Wurz, 2014, Fig. 1a). This has now changed. First, the region does have a richer archaeological record than widely appreciated (Wilkins, 2020; Coulson et al., 2022), though most excavated sites are from marginal locations relative to the interior basin as a whole. Second, genomic investigations have pointed to a similar 350 -200 kyr timeframe for modern human divergence in southern as in eastern Africa (Tishkoff et al., 2009; Henn et al., 2011; Chan et al., 2015; Schlebusch et al., 2021). Third, further DNA research has led to the claim that the Okavango-Makgadikgadi basin, in present day Botswana, was *the* 'homeland' region of anatomically modern humans, with subsequent environmentally-driven dispersal to other parts of Africa from c.130kyr (Chan et al., 2019, Fig. 1b). This claim is not only hotly disputed on genetic grounds (Schlebusch et al., 2021), but fundamentally challenges the emerging idea of African multiregionalism (Scerri et al., 2018). Nevertheless, it is important for at least placing the interior of southern Africa on the map of human origins research. In doing so this work has also highlighted the paucity of published archaeological evidence from the region (see Wadley, 2015; Burrough, 2016), as well as issues in the interpretation of its palaeohydrology and palaeoclimate histories (Moore et al., 2012). Robust palaeohydrological data from the region, as well as systematic archaeological analyses and excavations, are vital for testing the 'garden of Eden' dispersal hypothesis of Chan et al. (2019) that has proved very controversial (Schlebusch et al., 2021).

Central southern Africa primarily comprises the extensive dryland Kalahari basin, centred on Botswana but in essence extending from the Orange River in northern South Africa to north of the Okavango Delta, into Angola and the Zambezi River catchment in western Zambia (Fig. 2). We have been conducting multi-disciplinary, archaeological, palaeoenvironmental and Middle Stone Age resource use research in the Makgadikgadi basin and its fluvial inflows (Fig. 2) during the last decade, with this research in turn underpinned by palaeoenvironmental and initial archaeological investigations in the previous thirty years (e.g. Brooks and Yellen, 1977; Burrough et al., 2009a,b; Cooke and Paterson, 1960; Cooke and Verstappen, 1984; Robbins, 1989; Shaw, 1988; Shaw et al., 1997). The new research that facilitates the analysis in this paper commenced with reconnaissance archaeological surveys in 2007 and 2008 that led to further detailed survey investigations and excavations in 2016 and 2017. These investigations have in turn provided new data to assess MSA associations with environmental hydro-dynamics and to address questions of human mobility and movement in this palaeolacustrine landscape. Detailed research findings from the component parts of the research are presented in Staurset et al. (2022a and b) and Coulson et al. (2022) for archaeology, Burrough et al. (2022) for geochronology and basin dynamics, and Nash et al. (2022) for geochemical investigations of resource sourcing and mobility.

In this paper, we first examine issues surrounding how central southern Africa has become neglected archaeologically, and the consequences this has had for subsequent representations of the region in analyses of early human-environmental relationships. To provide context for this assessment, we briefly examine why eastern Africa has been so prominent in research that shapes the hominin-environment nexus, and at greater length, why in southern Africa coastal cave and rock shelter sites have become the primary focus of archaeological investigations, providing a sense of the gaps in research that our investigations have sought to fill. Second, we then integrate and summarise our new findings to address two issues that derive from the notion of an inhospitable interior, including Chan et al.'s (2019) 'dispersal from the Garden of Eden' hypothesis: a) to what extent was the Kalahari basin, and Makgadikgadi in particular, actually a region that became less hospitable from c.130 kyr, and b) how may hydrological and

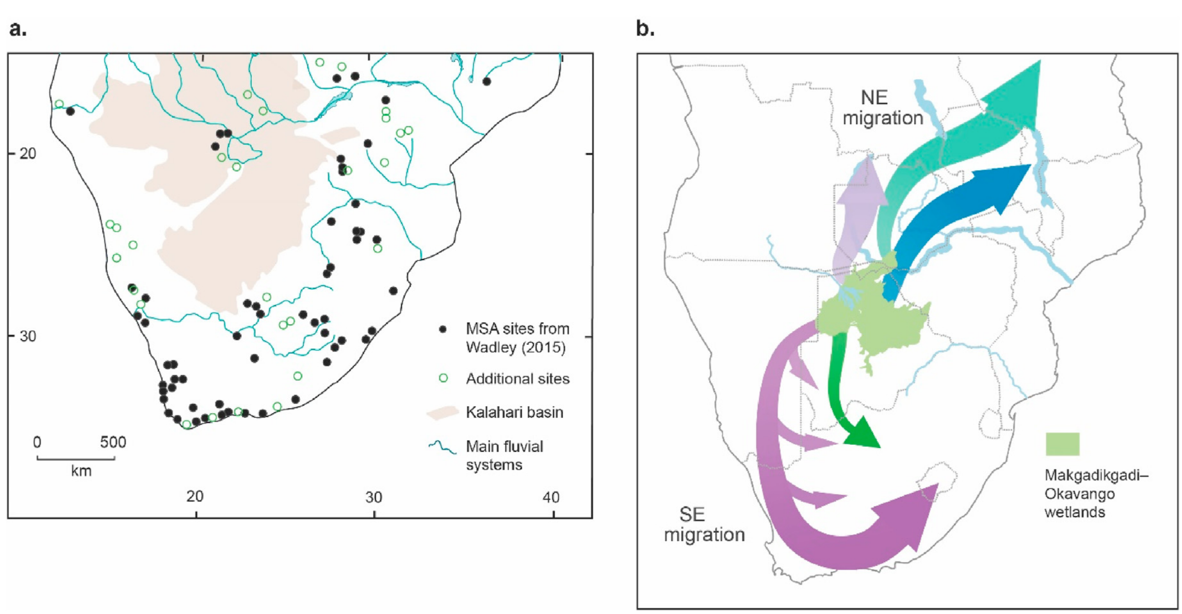

Fig. 1. **a**. Middle Stone Age site distribution in southern Africa included in Wadley's (2015) review of the region, with the interior largely devoid of sites. Individual site names have been removed and can be found in the original publication. Additional sites included in Burrough et al. (2019) are shown as open circles. The Kalahari basin is shaded. **b.** The 200-130ka ancestral human homeland of Chan et al. (2019) in the Makgadikgadi-Okavango basin (shaded) and inferred outward southeast and northeast migration trajectories.

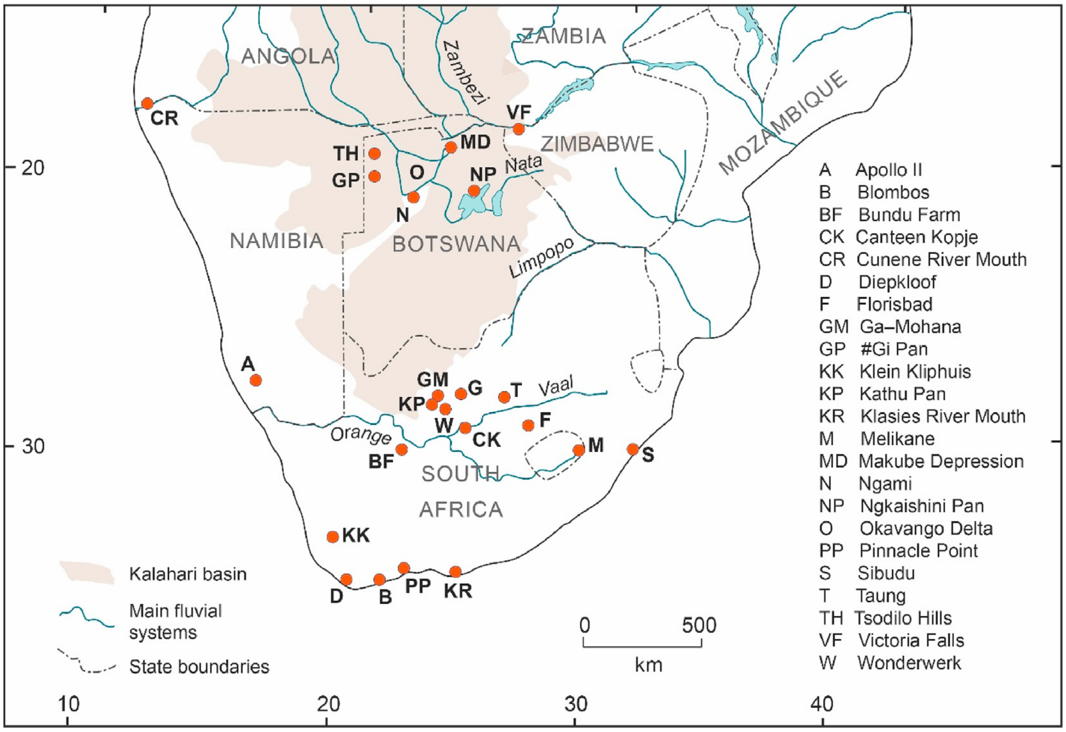

Fig. 2. Sites in southern Africa mentioned in the text. The extensive Kalahari basin, at the surface comprising in the main unconsoldated sands and silts, is shaded. Today, driest, arid conditions occur in its southwestern extreme of the basin (less than 150–200 mm mean annual rainfall), while over much of modern Botswana conditions are predominantly semi-arid (~200–500 mm mean annual rainfall). The Makgadikgadi Pans, which are the sump of the Makgadikgadi basin, are shown in darker shading, with Ntwetwe in the east, Sua Ntwetwe in the west.

landscape changes have contributed to patterns of human presence/absence in the basin during the MSA. Finally, we discuss the wider implications of these findings for debates about evolving human adaptability and mobility.

2. The pre-eminence of eastern Africa in interpreting the development of pre-human and early human-environment relationships

The East African rift valley, unlike many other regions of the African interior (Scott and Neumann, 2018), has structural and tectonic configurations that have facilitated preservation in the landscape of significant, co-located, archaeological and sedimentological sequences. These have allowed the relationships between environmental conditions and hominin development to be better understood, with investigations in Kenya's Olorgesailie basin being especially significant in this regard.

Excavations commenced in the 1940s (Leakey, 1952), and were reinvigorated from the 1960s (e.g. Isaac, 1977, 1978) with the benefit of robust age control (Baker and Mitchell, 1976). The development of detailed palaeo-landscape frameworks (e.g. Potts et al., 1999) have provided the context for analyses of hominin bone remains, extensive artefact collections, and sedimentary records that chart evolving hominin behaviour in a changing environment spanning much of the last 1.2Ma (Potts et al., 2018). With the integration of records from other hominin-occupied contexts in eastern Africa, notably Turkana (e.g. Coffing et al., 1994), Olduvai (e.g. Leakey, 1978), the Hadar Basin (e.g. Johanson et al., 1982), the Kaptherin Formation spring deposits west of Lake Baringo (e.g. Johnson and McBrearty, 2012) and the nearby Tugen Hills (e.g. Hill, 2002) and, coupled with long marine core palaeoclimatic records from offshore north east Africa (e.g. deMenocal, 2004), analysis of hominin relationships with, and responses to, changing palaeoclimates and resource availability has even been extended back to 5 Ma (Potts and Faith, 2015).

These important and influential studies have demonstrated the adaptive versatility characterising the immediate ancestors of *Homo sapiens* including those that marked the transition from the Early Stone Age (ESA) to the MSA (Potts et al., 2018), and the emergence of modern *Homo sapiens* and significant tool making technological innovations. These include the earliest recorded systematic blade production and Levallois core reduction (Johnson and McBrearty, 2012), dated to c.465–395 ka within Kapthurin sediments that fill the ESA-MSA transition gap in the Olorgesailie records, and long-distance raw material (obsidian) transport at 222.5 ka (Blegen et al., 2018). These innovations were born in the context of significant environmental variability (Potts, 1998; Potts and Faith, 2015), that in turn led to a diversity of landscape types being occupied by *Homo sapiens* during the MSA (Blinkhorn and Grove, 2018). Later technological advances, including the development of backed microliths recorded at Enkpune ya Muto (Ambrose, 2002) and Panga ya Saidi (Shipton et al., 2021), in southern Kenya, and Mumba (Diez-Martin et al., 2009), Kisese II (Tryon et al., 2018) and Nasara (Ranhorn and Tryon, 2018) in Tanzania, show the broadly coeval nature of the MSA-Later Stone Age (LSA) transition (c.57–40 ka ago) across the eastern African landscape.

Emerging from eastern Africa, therefore, has been a body of interdisciplinary research, involving archaic and ancestral human fossils, artefact analyses, sedimentological investigations and strong age control, that points to the growth, through the MSA, of modern human capacity to be less environmentally restricted than other, earlier, hominins. Furthermore, and of relevance to subsequent discussions, many of the excavations and finds that have yielded key records have been in open-air contexts, such as the earliest record of complex projectile development, c.80-100 ka ago, at Aduma, Ethiopia (Sahle and Brooks, 2019), as well as the extensive sites at Olorgesailie. Open site record preservation has been facilitated by rapid burial, particularly by volcanic sediments, but not excluding slope, spring, channel and lake deposits, many of which provide environmental signatures and materials that allow age control of faunal remains and artefacts (Potts et al., 2018).

3. The southern African legacy

Like eastern Africa, southern Africa played an important, but more challenging, role in early research into human ancestry. These commenced with the discovery of the ‘Taung child’ cranium in quarry limestone in present-day Northwest Province, South Africa (Dart, 1925), on the escarpment margin of the Kalahari basin. Subsequent finds in other quarries and cave systems, including the Florisbad cranium (Dreyer, 1938) and the more recently discovered 1500-plus bones of *Homo naledi* (Berger et al., 2015), have added further to successional debates leading to, and within, the *Homo* genus.

Unlike research from eastern Africa, however, there have arguably been relatively limited contributions to the development of ideas regarding the earliest archaic and ancestral human environmental adaptations and behavioural developments, especially with respect to sites with bone remains. This has been due to a combination of the lack of primary context information for finds (e.g. discoveries made during quarry excavations often lost their primary contextual information), taphonomic issues surrounding the source of bone accumulations in caves (Brain, 1969, 1978), a lack of detailed palaeoenvironmental stratigraphy, as well as chronological control issues (Stringer, 2015; Scott and Neumann, 2018). *H. naledi* for example is dated to the wide window of 414–236 ka (Dirks et al., 2017), and the Florisbad cranium to 300-250ka (Grün et al., 1996). Only now is a reliable chronology being developed for the extensive ESA to LSA deposits of Wonderwerk Cave, including the antiquity of the ESA Acheulian deposits (Shaar et al., 2021) and the timing of the ESA-MSA transition, associated with the Fauresmith industry, dated within 240–150 ka (Chazan et al., 2020).

From the 1930s onwards, there was significant interest in the lithic artefacts associated with river gravels and terraces throughout southern Africa. These notably included the Vaal River gravel artefacts (and faunal remains) in South Africa analysed by Van Riet Lowe (1935), Söhnge et al. (1937), Partridge and Brink (1967), Butzer et al. (1973) and others, and sites along the Orange River (Sampson, 1972). Chronometric (Gibbon et al., 2009) and geomorphological (Lotter, 2020) reassessment of Vaal terrace deposits has in recent years led to reappraisal of the antiquity and environmental context of the earliest artefacts, affirming the synchronicity of the earliest tool manufacture in southern and eastern Africa and better characterising the environmental context of site formation. The artefacts associated with the open-air sites at Canteen Kopje (also Klipdrift: Haughton, 1921) on the Vaal have particular importance in understanding the transition from ESA to MSA. Kuman et al. (2020) have consequently argued that the Fauresmith artefacts from the Vaal deposits are indicative of a slow and complex transition to the MSA, with technological innovations in core production beginning in the late Acheulian (ESA) and linking through to the Levallois cores of the MSA (Li et al., 2017).

Important, often now neglected, investigations also occurred in river systems on the northern and eastern margins of the Kalahari basin. These include the analysis of ESA to LSA artefacts from the staircase of river terrace and Kalahari Sand deposits associated with the Zambezi valley both above and below Victoria Falls (Clark, 1950; Bond and Clark, 1954); extensive artefact spreads in the valley terrace deposits of Zambezi tributaries in modern Zimbabwe (Jones, 1944; Bond, 1946) and in the Nata River in eastern Botswana (Bond and Summers, 1954); and MSA and LSA sites on the Upper Zambezi in western Zambia (Phillipson, 1968, 1975, 1976, 1977). The Upper Zambezi sites have recently been given chronometric control by Burrough et al. (2019), while new chronologies are being developed for the Victoria Falls sites that provide a maximum age for the transition to the MSA in this area of 590 ± 86 ka (Richter et al., 2022).

The important overview of records from MSA sites in southern Africa provided by Wadley (2015) has suggested that the interior of the subcontinent was occupied prior to 130 ka, with subsequent dispersal driven by drying. Wetter, and more resource-rich, coastal and upland areas, became the dominant foci of human activity. Topographies in these regions provided caves and rock shelters where accumulated sedimentary matrices have preserved long archaeological sequences rich in lithic, faunal and other remains, many suitable for dating. Investigations of these deposits have led to critically important discoveries, which infer that many MSA innovations occurred at the coast (Jacobs et al., 2008; Douze et al., 2015). Major sites record for example the early use of ochre c.100 k yr ago (Blombos Cave: Henshilwood et al., 2011), the production of ornamental beads (Blombos: Henshilwood et al., 2004), the use of incised ostrich eggshell water containers (Diepkloof Rock Shelter: Texier et al., 2013), the development of sophisticated diets (Pinnacle Point Cave: Marean et al., 2004; Marean, 2014), the strategic selection of raw materials for tool making (Klasies River Mouth Caves: Wurz et al., 2018; Sibudu Cave: Backwell et al., 2008), and abstract art dated to c.70 k yr ago (Blombos Cave: Henshilwood et al., 2018). Wadley (2015) adds a cautionary note not to solely infer coastal predominance, as other key cave and rock shelter sites occur in more diverse ecosystems including forests (e.g. Sibudu: Wadley, 2006; Wadley and Kempson., 2011), semiarid environments (e.g. Apollo 11 Rock Shelter: Wendt, 1972; Vogelsang et al., 2010; Lombard and Högberg, 2018; Klein Kliphaus Shelter: Mackay, 2010; Spitzkloff Rockshelter: Dewar and Stewart, 2012) and mountains (e.g. Melikane Rock Shelter: Stewart et al., 2012; Pazan et al., 2022). The majority of sites are however either associated with the escarpment that rings the sub-continent, including the Drakensberg Mountains and Namibian uplands, or the coast, rather than the interior, though the value and significance of interior, open air sites is beginning to emerge, as exemplified by the recent work at Bundu Farm in the Karoo, where MSA material dated to 300–150 ka is linked to cooler and wetter grassland conditions (Kiberd and Pryor, 2021).

4. The empty interior? Taphonomy and the value of open-air sites

The dryland interior of southern Africa does not figure large, or even at all, in most accounts of southern Africa's evolving MSA, especially after 130 kyr (Henshilwood and Lombard, 2013; Wurz, 2014), appearing as an empty space on maps of MSA research (Wadley, 2015, Fig. 1). Put simply, much of southern Africa's interior, especially the extensive Kalahari, has been regarded as a marginal area, perhaps uninhabited for long periods (Walker, 1998). As a result, the ‘dominant narrative of *H. sapiens* origins being intrinsically tied to the coast and marine resources, with little or no contribution from the Kalahari Basin’ (Wilkins, 2020:2) has emerged.

Given the limited occurrence of rock shelters and caves – the preferred contexts for southern African excavations – the flat, largely sandy, geomorphological context of much of the 2 million km^2 Kalahari basin (Thomas and Shaw, 1991) has created taphonomic effects in archaeological research. Excavations from the

Tsodilo Hills in Botswana (Fig. 2), at White Paintings Rock Shelter (Robbins et al., 2000a) and Rhino Cave (Robbins et al., 1996, 2000b; Coulson et al., 2011), the long, discontinuous, sequence from Wonderwerk Cave (Brook et al., 2010; Bamford, 2015; Chazan et al., 2018), and nearby Ga-Mohana Hill rock shelters (Wilkins et al., 2020, 2021), are exceptions. The Tsodilo Hills comprise three inselbergs located within the otherwise flat sandy and alluvial Kalahari plains of northwest Botswana. Wonderwerk is a karstic cave, and Ga-Mohana a series of rock shelters, occupied during regionally-wetter conditions at 105 ka (Wilkins et al., 2021), in the dolomitic limestone of the Kalahari's southern escarpment in the Northern Cape, South Africa. These important sites are the source of valuable data on the region's MSA and on associated resource use, but they are not fully representative of the landscape, or of drier conditions, as a whole.

At least until recently, challenges of accessibility may also have contributed to the reluctance for archaeological venture in the flat Kalahari interior (Robbins et al., 2016; Coulson et al., 2022). Rather prosaically, therefore, the perspective of an empty interior may at least have some of its foundations in the patterns, practices, opportunities and choices for archaeological research. Only two open MSA sites have, until now, been excavated in any detail within the Kalahari basin. These are ≠Gi Pan, an open-air site in northwest Botswana close to the Namibia border (Brooks and Yellen, 1977; Helgren and Brooks, 1983), and Kathu Pan, close to the basin margin in the south (Chazan et al., 2012; Wilkins et al., 2012). The excavations at ≠Gi revealed a considerable quantity of faunal remains alongside characteristic MSA lithic artefacts, including bone remnants of three now-extinct species, *Equus capensis* (giant zebra), *Pelorvis antiquus* (giant buffalo) and *Megalotragus proscis* (a giant antelope of the wildebeest/hartebeest sub-family). At Kathu, an ESA living surface (Chazan et al., 2012; Walker et al., 2014), the ESA-MSA transition (Porat et al., 2010) and evidence for early blade development (Wilkins and Chazan, 2012) are reported. Like the Kalahari's rock shelter and cave excavations, these sites are also relatively close to the basin's margins, rather than its core. MSA and LSA artefacts are also detailed at several other open-air sites (Helgren, 1984; Yellen and Brooks, 1989; Robbins, 1989; Robbins et al., 2008; Walker, 2009).

It should also be noted, especially when compared with the long timespan covered by records from eastern Africa, that ESA artefacts have not yet been discovered in the few Kalahari cave and rock shelter sites. Robbins et al. (2016) suggest this may be due to the depth of the excavations not reaching ESA levels, rather than to a real absence. The ESA has been recorded in several open-air contexts around pans and valleys (Robbins and Murphy, 1998; Coulson et al., 2022). One of these, Ngxaishini Pan, also has associated large faunal remains (Robbins et al., 2016), though systematic investigation has not been published and much of the material has unfortunately now been removed by visitors to the pan. As well as the sites referred to above, the sense of an empty interior contrasts with both many ‘grey literature’ reports of surface sites that range from ESA to LSA (Burrough, 2016), as well as now largely forgotten scientific reports of abundant Palaeolithic sites throughout the Kalahari basin (e.g. Wayland, 1950; Cooke, 1979; for a new overview see Coulson et al., 2022).

There is also a sense that the benefits of excavating open-air surface archaeology sites has been generally undervalued in southern African research (Forssman and Pargeter, 2014). Several reasons may underpin this: the assumed risks of post-occupation disturbance and weathering (Oestmo et al., 2014); potential difficulties in establishing chronologies for open sites (Knight and Stratford, 2020); and the assumption that rock shelter and cave sites provide rich, reliable, records often spanning wide temporal ranges, allowing technological shifts to be analysed (Marean, 2016; Roberts et al., 2016; Reynard and Henshilwood, 2019).

Butzer (1984) noted that without recourse to open sites and through over-reliance on the records from caves and rock shelters, incomplete or biased interpretations of early human behaviour in southern Africa could result. The crucial role open-air sites can play, especially in understanding dimensions of behavioural and resource use patterns, has been widely demonstrated by research in eastern Africa. It has also sometimes received acknowledgement in southern Africa (Klein, 1976; Kuman, 1989), while a recent assessment has identified the potential contributions that whole-assemblage analyses can bring to interpretations of open landscape use (Schoville et al., 2022). There has, relatively recently, been some redress in open-air site investigation, in coastal situations (e.g. Fuchs et al., 2008; Kandel and Conard, 2012; Oestmo et al., 2014), on the southern Kalahari margin (Wilkins and Chazan, 2012; Walker et al., 2014), in Namaqualand (Dewar and Stewart, 2017), at Bundu Farm in the northern Karoo (Kiberd and Pryor, 2021) and at the Cunene River mouth on the Angola-Namibia border (Nicoll, 2010), though the research effort remains substantially less than that for rock shelter sites.

In summary, for the modern dryland interior of southern Africa – where the scarcity of cave and rock shelter sites is a facet of the region's geological and geomorphological setting – we argue that *not* to investigate open-air sites is at best to deny significant prospects of understanding more widely and more completely the dynamics and environmental associations of early human presence, or at worst is to assume that large areas went largely unoccupied for long periods. The gains that can be made, which are so clearly illustrated by the discoveries from studies such as Helgren and Brooks (1983), Helgren (1984) and Robbins (1989), need to be replicated many times over before regional answers to critical questions in early human history can begin to be established. Following a brief introduction to the study region, we draw on new landscape (Burrough et al., 2022), archaeological (Staurset et al. (2022a and b; Coulson et al., 2022) and resource (Nash et al., 2022) data to contribute environmental and archaeological perspectives to debates around early human presence in the southern African interior and Chan et al.'s (2019) Kalahari dispersal theory.

5. The Makgadikgadi basin

The Makgadikgadi basin is the end point of southern Africa's extensive internal endoreic drainage system (Thomas and Shaw, 1991) with feeder fluvial systems rising in the tropical northern areas of Zambia and Angola, as well as in western Zimbabwe. Now-fossil valley systems would also have supplied flow to the basin from western and southeast Botswana, although the timing of all but the most recent events is poorly constrained (Shaw et al., 1992; Nash, 2022). Today's basin sump areas, Ntwetwe and Sua pans, are for the most part, extensive salt flats that receive episodic austral summer shallow (~<1m maximum) inundation sourced in the main from localised rainfall, groundwater inflow (McCulloch et al., 2010), the Nata and other small rivers draining from northeast Botswana and western Zimbabwe (Burrough et al., 2022). The Boteti River links the system to the Okavango Delta to the northwest. Floodwaters from the Okavango occasionally reach the basin in late winter months but would have served as the primary inflow to the basin during wet periods in the late Quaternary. Modern rainfall is seasonal, occurring predominantly in the austral summer months (October–April), with mean annual rainfall at Nata, on the eastern edge of Sua Pan, reported as 453 mm (Makgadikgadi Framework Management Plan, 2010) or, more recently, 335 mm (www.weatheratlas.com), representing semi-arid conditions. The basin as a whole, which at its maximum extent covers c.90,000 km^2 has a hydrological history that includes major palaeolake phases before (McFarlane et al., 2005) and during ((Burrough et al., 2009a) the Quaternary. Late Quaternary lake stages of up to 66,000 km^2 (White and Eckardt, 2006) are evidenced through chronologies derived from the distinctive shoreline features (beach ridges) that formed during lake high stand phases, found especially on the western margins of the main Makgadikgadi sump and the Ngami and Mababe sub-basins (Burrough et al., 2009a,b). Burrough et al. (2022) provide additional lake stage ages from basin floor sediments, which are integral to interpreting the environmental context of the archaeology of the system. Lake stages are related to a set of complex factors that extend beyond increased local rainfall, with flow from the wider catchment, which extends up to 1000 km^2 to the north into the wetter tropics, being especially significant (Burrough et al., 2009b).

In 2008 and 2009 two of the authors (DSGT, SLB) conducted reconnaissance surveys of archaeological sites in the Makgadikgadi basin, particularly in its western part, the >3000 km^2 Ntwetwe Pan. Numerous MSA sites and scatters were recorded on the floor of Ntwetwe, at distances of up to 20 km from the modern pan margin, within the deepest part of the Makgadikgadi system. During the main study in 2016 and 2017 we recorded through further survey over 60 additional archaeological locations in the system (Fig. 3), including ESA, MSA, LSA and pastoralist sites (Coulson et al., 2022). We also extended the survey to cover sites within inflowing channel systems, including, as well as new sites, locations previously reported in the Boteti (Wayland, 1950, Campbell, 1988) and Nata (Cooke, 1967), and on the margins of the lake system. We did not focus our efforts on the eastern sector of Makgadikgadi, Sua Pan, though previous surveys (see summary in van Waarden, 2010, 2011) suggest this deserves detailed future survey. The modern hydrology in the basin, including more frequent inflows from the Nata and other seasonal rivers that debauch from Sua Pan's eastern margin, may, in the northern and central parts of the pan floor, inhibit archaeological visibility through sediment inputs (Bryant et al., 2007) and the subsequent development of surface crusts (Nield et al., 2016).

6. Human use of the landscape: limited, or not?

A facet of Chan et al.'s (2019) origins and dispersal model is the implication that the Makgadikgadi-Okavango basin was the source area for anatomically modern human dispersal across Africa, c.130-110 kyr, with northeast and southwest migration trajectories based on modern population DNA analyses, as well as a residual population in the region of the lake basin. As noted in section 1, in other studies the interior is shown as a region lacking key MSA sites (Wadley, 2015, Fig. 1a). In Coulson et al. (2022) we show that MSA sites are in fact widely found in the regional landscape. An issue however is that very few sites had been excavated or even tested to establish the nature of post-130ka MSA landscape use in the vicinity of Makgadikgadi: the only previous detailed excavations in the region were to the northwest of the basin at Tsodilo Hills (Robbins et al., 1996, 2000a; Coulson et al., 2011) and further west at ≠Gi (Helgren and Brooks, 1983).

Our focus for detailed analyses was sites within Makgadikgadi itself (Fig. 4). The full excavations, reported in detail in Staurset et al.

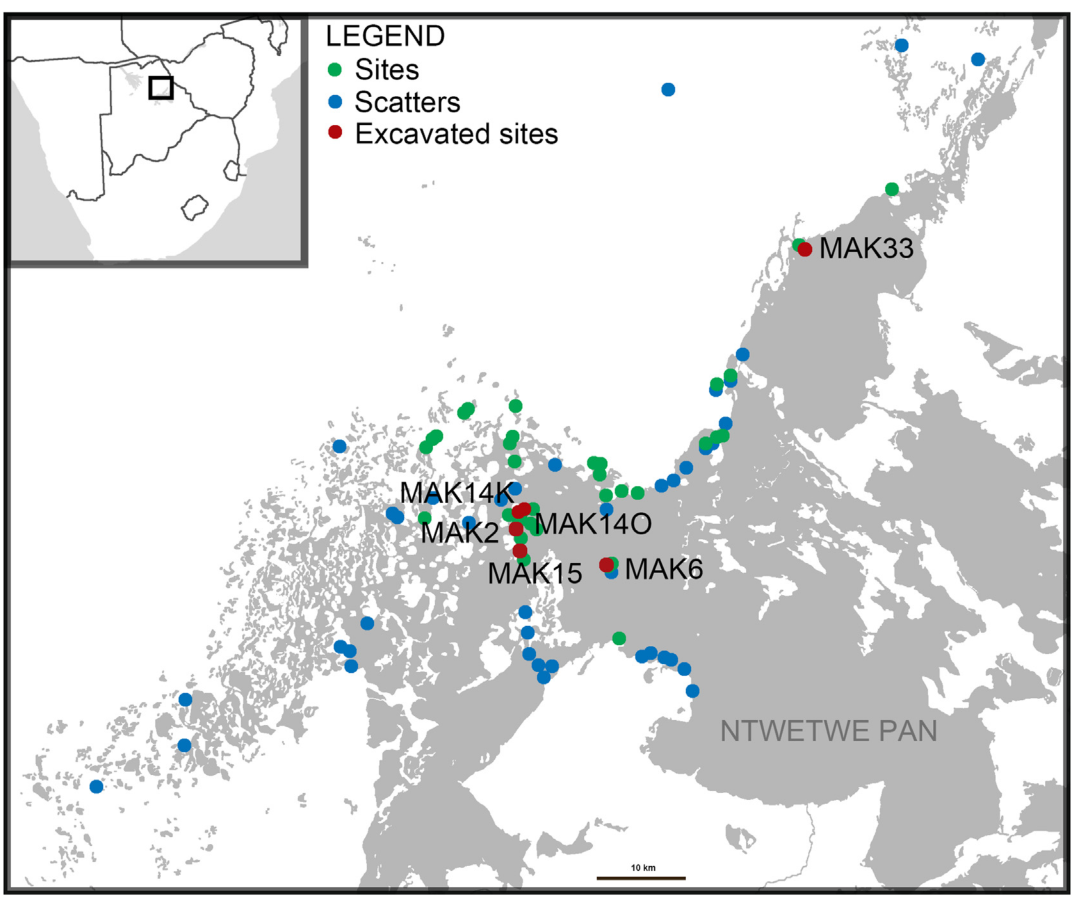

Fig. 3. Location of surveyed and excavated archaeological sites and artefact scatters in Ntwetwe Pan, western Makgadikgadi basin. Details of excavations can be found in Staurset et al. (2022a).

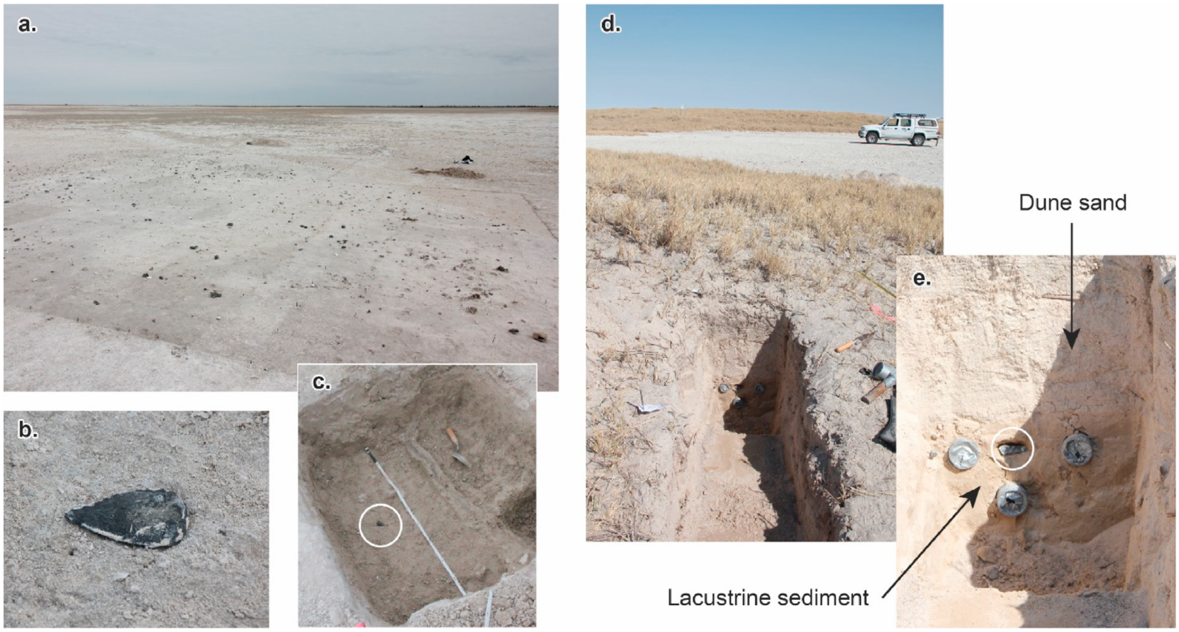

Fig. 4. Artefact contexts within Ntwetwe Pan. **a.** Excavation site MAK33. The surface has been cleaned of loose sediments, revealing blocks, cores and artefacts *in situ*. View looking south. **b.** Silcrete point on the surface of MAK33. **c.** Exploratory pit on the south margin of MAK33. Circle highlights an artefact found at c 30 cm depth. **d.** Test trench through a small dune island at site MAK14K. The trench revealed the contact between underlying lacustrine sediments and overlying dune sand, shown in **e.** An artefact below the contact of the two units is circled. The lowest three of five sample points for OSL dating are also shown, two further samples were subsequently taken vertically above the contact zone, in the dune sand. Results, detailed in Burrough et al. (2022), were 70 ± 10 yrs and 150 ± 10 yrs in the dune sand, and 57 ± 8 ka and 55 ± 8 ka for the two lacustrine sediment samples in the same plane as the artefacet. The lowest sample dates to 84 ± 10 ka.

(2022a), show that MSA use of the *dry* basin floor was systematic, with distinct behavioural traits evidenced from our analysis of the materials used for artefact manufacture. Large (~15 cm diameter) blocks of silcrete, as well as cores and blanks, were deliberately moved distances of between 7 and 55 km from defined source outcrops (Nash et al., 2022). These were used to manufacture, on site, characteristic highly retouched unifacial and bifacial points using chiefly Levallois, Kombewa and discoidal reduction strategies (Staurset et al., 2022a).

We also recorded MSA sites on the margins of the present-day Ntwetwe Pan and at smaller pans in the wider basin landscape, but these sites have not yet been excavated. The vast majority of other published reports of open-air MSA sites in the region are along riparian corridors, particularly the Boteti (Cooke, 1979, van Waarden, 1991) and Nata (Bond and Summers, 1954) rivers, both of which drain into Makgadikgadi, or on the margin of small pans (Cooke and Paterson, 1960; Brooks and Yellen, 1977; Robbins, 1989). This suggests that immediate proximity to water may have been a key facet in MSA environmental use (see Coulson et al., 2022). Importantly, the distribution of sites we have recorded and excavated on the floor of Ntwetwe Pan indicates a geographically wider use of this environment, that occurred during phases when the pan was at the least largely dry and likely markedly different, especially in terms of vegetation cover, from the environs surrounding the pan, as is the case today.

7. Basin dynamics and archaeological visibility in the Kalahari interior

Understanding the hydrological dynamics of Makgadikgadi, and their sedimentary consequences, is important for explaining the presence of relatively undisturbed archaeological sites on the basin floor. Our research has allowed us to place MSA use of this environment within a chronologically robust framework for the basin's late Quaternary hydrodynamics derived from dating both shoreline and basin floor sediments.

The surface occurrence of possible ESA artefacts within the confines of Makgadikgadi's margins (McFarlane and Segadika, 2001) contributed to Moore et al. (2012) positing mid-Pleistocene antiquity for a deep lake in the basin, arguing that *in situ* artefacts could not survive disturbance by a large water body. A significant body of age-controlled sedimentary data, however, indicates the hydrological dynamism of Makgadikgadi through the last ~ c.140 kyr, including large water bodies up to up to 66,000 km^2 that reached depths of 40m above the present basin floor (Burrough et al., 2009, 2022). Sandy shoreline ridges, particularly prominent in the western margins of Makgadikgadi, are the residual morphological expressions of lake highstands, up to 945m above sea level (Burrough et al., 2009a,b), while other parts of the basin margin are represented by an escarpment in the south, and faultline ridges in the northeast of Ntwetwe Pan. MSA sites have been documented, but not investigated in detail, in association with these last two margin contexts (Coulson et al., 2022).

It is significant from an environmental perspective, that despite invoking Makgadikgadi basin drying as the driver of dispersal, a residual population was identified in the region (Chan et al., 2019). In fact, the lake level curve for Makgadikgadi, derived from both shoreline optically-stimulated luminescence (OSL) ages (Burrough et al., 2009a,b) and recalibrated radiocarbon ages, identifies one or two lake phases between c.130 and 80 kyr followed by a period of desiccation (Burrough et al., 2022).

The MSA archaeological sites we have investigated (Staurset et al., 2022a, b) lie on the modern basin floor at 904–907m asl (Fig. 4). We also observed a single handaxe roughout near one of our basin sites, MAK33, in the northeastern arm of Ntwetwe Pan (Coulson et al., 2022), and an ESA quarry scatter with evidence of early stage handaxe production near the north-western margin ridge of Ntwetwe. In Burrough et al. (2022) we unequivocally demonstrate how Late Quaternary lake level fluctuations and the presence of undisturbed MSA sites are *not* contradictory situations. Indeed, they are geomorphologically complementary. Fluvial inflows during lake high stages brought muddy, silt-rich sediments that buried and protected artefacts that had accumulated on the basin floor when hydrological conditions facilitated human access. Sediment deflation during dry stages, including today (Bryant et al., 2007), has removed sediment overburden, revealing artefacts at the surface once more, a process also noted as important for site visibility in some southern African coastal locations (Dietl et al., 2005; Oestmo et al., 2014).

By OSL-dating lake floor sediments associated with MSA material (Fig. 4), we have therefore been able to identify 80 ± 6 ka - 72 ± 5 ka and post-57 ± 10 ka as times when the basin floor was utilised by early humans (Burrough et al., 2022). Our excavations were conducted at only a small fraction of the total number of MSA sites on the basin floor, so we cannot exclude the possibility of a wider timeframe of dry basin floor use being present in the deflation-exposed MSA sites in landscape. We can also note that the most securely dated MSA elsewhere in the Kalahari, at ≠Gi (Helgren and Brooks, 1983), falls within the bracketed age range of the Ntwetwe MSA.

Aeolian dune islands on the floor of Ntwetwe Pan (Richards et al., 2021) also play an important part in archaeological visibility in Makgadikgadi. Not only do they locally protect basin floor sediments and interspersed artefacts (Burrough et al., 2022), they are the site of post-MSA archaeological material that to date we have not found in abundance on the basin floor itself (Coulson et al., 2022). Ntwetwe dune islands are relatively young, post-dating the mid-Holocene (Burrough and Thomas, 2013) and in many cases only dating from the last few hundred years (Richards et al., 2021; Burrough et al., 2022). Site MAK6 (latitude 20.643S, longitude 25.212E) is a relatively large dune island known locally as Gabasadi Island. Here LSA material from the dune upper sediments has been OSL dated to 1.28 ± 0.2 ka - 0.33 ± 0.02 ka (Burrough et al., 2022) and includes microblades, cores and ostrich shell (Coulson et al., 2022). At MAK1, a dune island on the pan floor, fragments of an undecorated pastoralist pot (see Coulson et al., 2022) made predominantly from tempered charcoal was found washing out from the surface of a dune island, the main body of which accumulated between 1.6 ± 0.2 ka and 0.9 ± 0.02 ka. These fragments were directly dated by both radiocarbon and OSL to 570 ± 32 cal ^{14}C years and 450 ± 100 yrs respectively. While wider systematic investigation is desirable, these examples illustrate that post-MSA the basin was also utilised by humans at-distance from the margins of the system, though it is the extensive MSA sites that offer the most tantalising glimpses into early human basin use.

8. Discussion: implications from Makgadikgadi for human adaptability and mobility in southern Africa

In the Kalahari, Helgren and Brooks (1983) provided an early environmental assessment of the hydrological context of occupations from the sedimentary units at ≠Gi. The modern pan at that site is situated in the shallow Dobe valley, with the sedimentology of the MSA units, dated to 77 ± 11ka, interpreted as representing semi-arid conditions even drier than those occurring today. Elsewhere in central southern Africa, Barham (2000) hypothesised from research in Zambia that periods of regional drying may have seen river valleys, including the perennial, distant-sourced, Upper and Middle Zambezi on the northern margins of the Kalahari, becoming refugia when more water-challenged sites were abandoned. The presence of MSA material in the Kalahari's Boteti and Nata valleys (Bond and Summers, 1954; Cooke, 1967; van Waarden, 1991) has also suggested a preference for MSA sites being close to water resources. These rivers are today ephemeral, with the Boteti recording decades of both flow and no flow in the recent historical period, linked to spatially variable channel dynamics within the feeder Okavango Delta. Coulson et al. (2022) also identify MSA material within the fossil Okwa and Kaudum valleys, which do not contain sedimentary deposits that help establish whether flow occurred at relevant timescales.

From the points above, it should not be assumed that the presence of archaeological sites in dryland valleys necessarily represent occupation at times of perennial flow or as refugia; indeed, the evidence from ≠Gi is to the contrary, while in the Boteti, some sites, such as Samedupi (Wayland, 1950; Cooke, 1979) would have been at least partially underwater at times of river flow. Channel floors and riverbanks, and the lithologies that they can expose, may have been an important attraction to early *H. sapiens* as a source of raw materials for lithic manufacture, particularly in exposure-limited landscapes as flat and generally sandy as the Kalahari. Valleys should not therefore simply be viewed as attractors in terms of water and the presence of animals to hunt: other factors may have played a role too.

8.1. Adaptation in and to Makgadikgadi

The evidence we have accrued from our excavations, palaeoenvironmental assessments and examination of lithic raw material sources point to a number of notable MSA adaptations within, or to, the specific conditions of a dry Makgadikgadi basin. The sheer number of recorded sites shows that MSA presence was not a random, limited occurrence. Lithic raw material movement over many tens of kilometres to facilitate tool manufacture is evidence of systematic, planned, behaviour. This includes the selection of silcrete raw material from specific sites in the basin (Nash et al., 2022), which contrasts with material movement over hundreds of kilometres reported for artefacts at Tsodilo Hills (Nash et al., 2013, 2016). The selection and nature of transport of silcrete suggests an adaptation not only to what was available for tool manufacture but also a flexibility of behaviour. Rather than manufacturing tools at source areas, the presence of blocks and cores at several sites is indicative of an element of pre-planning: a preparedness to carry material, from specific sources potentially selected because of the quality and suitability of material for knapping, to allow tool manufacture to vary according to what was needed, where and when.

The lithic industry from Ntwetwe, however, has a more restricted toolkit, including larger points (Staurset et al., 2022a), manufactured through different production techniques compared to the MSA lithics at ≠Gi. Production also afforded stringent criteria for acceptable tools, where large numbers of points with only minor asymmetries or edge defects were discarded in late stages of production (Staurset et al., 2022b). The lack of impact fracturing on artefacts, and the lack of reworking or cannibalizing of points to make other pieces, is a further difference between the Makgadikgadi and #Gi artefacts.

We cannot detail the precise degree of dryness in the basin at the times of MSA use. However, it must have been dry enough for MSA people using the basin floor to stop and knap artefacts, as evidenced by the nature of the lithic remains found at our excavated sites and their refitting (Staurset et al., 2022a). Under modern, semi-arid conditions, the basin floor is accessible for several months each year, especially during the austral winter dry season months. But after local rainfall events, and in zones affected by seasonal or episodic inflow – such as where the Nata River enters Sua Pan in the east, the Boteti enters the Makgadikgadi basin in the southwest, and areas of seasonal groundwater seepage, such as the northern parts of Ntwetwe Pan (McFarlane and Long, 2015) – often extensive bodies of standing water, at least tens of centimetres deep, occur on the basin floor. This would make passage on foot impossible or extremely challenging over large areas. It would also flood low-lying areas of silcrete, limiting access to key resources for tool manufacture. As drying proceeds, standing water retreats to isolated brackish pools of water, used extensively today by herds of seasonally migrating ungulates (Bartlam-Brooks et al., 2013; Brooks and Harris, 2008), while the wider pan floor reverts to a highly saline and open environment. We can by inference propose that the very presence of numerous MSA sites on the basin floor, such as our excavated sites in the area of MAK14 in central Ntwetwe, point at adaptation to being away from immediate fresh water sources, towards an environment that was at least as dry as modern conditions.

The MSA sites within Ntwetwe Pan, and many of the silcrete raw material source areas used for artefact manufacture, are at considerable distance, and certainly more than a day's walk from, potential fresh water sources, distances that hunter-gatherers are able to traverse (Brooks, 1984; Brooks and Yellen, 1987). The scale of mobility inferred by the great distances between artefacts excavated from the Tsodilo Hill sites (Coulson et al., 2011) and their material source areas through the northern Kalahari (Nash et al., 2013) also imply a disconnection during the MSA from immediate water sources. There was however little evidence of material associated with water-carrying containers at our Ntwetwe MSA sites. Small pieces of ostrich eggshell were found at several excavated sites (Staurset et al., 2022b), and Robbins (1989) reported fragments from investigations at Kudiakam Pan, but in neither case can it be established whether these are fragments from water containers or simply part of the background environmental noise to be found at sites within a dryland context.

We can suggest that what we have recorded at Ntwetwe represents an adaptation of lithic production and mobility patterns to a dynamic (seasonally wet/dry) or an arid (fully desiccated) and resource-rich pan landscape. The MSA people of Makgadikgadi were certainly not limited to the resources and opportunities presented by riverine conditions, ranging considerable distances from readily available fresh water. Raw materials did not have to be imported over hundreds of kilometres, but were available within the basin itself and even on the dry basin floor. Ready access to an extant silcrete resource may perhaps have been an attractor to the degree that it even afforded the luxury to abandon almost perfect tools during knapping (Staurset et al., 2022a). That raw material was being moved, and tools manufactured, is indicative of purposeful behaviour. While the rationale for this can currently only be speculated upon, the modern dynamic of seasonal wildlife movement into the basin to graze on salt-tolerant grasses associated with brackish pools may give an insight to a possible reason for MSA people to themselves move within the basin system (Robbins, 1989; Burrough, 2016).

8.2. A wider space for adaptation?

Changes in hydrological regimes through the middle and late Pleistocene may well have caused population separations and remixing (Klein, 2019). There is however clear evidence from this study that drying did not cause wholescale regional abandonment of the southern Africa interior, an inference that has been a significant part of subcontinental MSA analyses. Indeed, environmental variability, including aridity, may even have facilitated necessary but purposeful adaptations to specific environmental conditions. Adaptability is a trait of modern humans and presupposes behaviours such as knowledge transmission (knowing where to find resources) and pre-planning (the need to move and take and carry resources for a specific purpose or to a specific place).

Undoubtedly the opportunities available in coastal locations, including caves for shelter and food resources such as shellfish, presented major opportunities for MSA people in the southernmost part of Africa, with numerous archaeological sites demonstrating innovativeness and expansion of the human ecological niche (Marean, 2016). Based on our data from Makgadikgadi, we would however challenge any notion that MSA innovation and niche expansion were confined to these wetter or very resource rich locations. Indeed, McBrearty and Brooks (2000), and recently Wilkins (2020), have from the Kalahari excavations at ≠Gi, Wonderwerk and Ga-Mohana argued that many important behavioural innovations have early origins in these Kalahari sites, and may even pre-date their coastal counterparts. We can also contest the notion that populations in central southern Africa were in any way unlucky 'residuals' of a dispersed greater population (Chan et al., 2019), implying some form of inferiority of decision making or behaviour. What we see is evidence for repeated, and decision-based, use of the dry basin floor of Makgadikgadi by MSA populations during times of low lake stands. It can also be posited that the dry basin floor provided access to high-quality fine-grained silcrete: Makgadikgadi was certainly not a resource-poor environment for tool-manufacturing groups. That prepared and unprepared cores, as well as blocks of this material, were selected and moved within the pan context implies forward thinking regarding raw material needs for future use (cf. Potts, 1991). It is not possible at this stage to establish what MSA people were actually doing in Makgadikgadi, though the toolkits manufactured, and the seasonal use and migratory habits of herds of ungulates today during dry conditions, may point to the basin being an excellent environment in which to flexibly hunt over extensive areas. We suggest therefore that the dry pans of the southern African interior, such as Ntwetwe, offered opportunities for niche development, innovation in resource provisioning and selection, and opportunism during the MSA.

9. Conclusion

Drylands are spaces of environmental opportunity, a facet long recognised in anthropological and archaeological research in eastern Africa (Potts, 1998; Potts and Faith, 2015). Rather than simply driving dispersal, dry and variable conditions may have facilitated adaptation, examined in an eastern African context by Grove (2016), where xerophytic dry environments are regarded as core landscapes for the MSA (Timbrell et al., 2022). In southern Africa, by contrast, dry conditions have been conceived to be an obstacle to innovation, and even to occupation, but this view is changing (Wilkins, 2020).

Schoville et al. (2022) argue, using evidence from the southern Kalahari margins, that behavioural plasticity, in the form of flexible foraging strategies, was a characteristic of MSA adaptation in the context of variable water availability and water stress. Our research in Makgadikgadi further enriches understanding of MSA behaviours in southern Africa's drylands. The wide spaces of the saline basin floor present evidence of successful adaption to variable and potentially challenging environmental conditions in the heart of this dryland region.

Here, hunting, provisioned by knowledge of the availability of the raw material, silcrete, necessary for tool manufacture, was the probable motive for purposeful and systematic human use of this seemingly challenging environment. That this occurred many times, evidenced by the numerous open-air MSA sites and scatters on the pan floor, indicates a systematic untethering from predictable and permanent fresh water sources. Distance of movement was not a limiting factor within these MSA groups: we must assume, though cannot yet evidence, that drinking water was carried, along with the raw materials for tools, as part of utilisation strategies. A further notable consequence of our findings is that all our sites in the open expanses of the interior Kalahari are a considerable distance from rock shelters and caves: it is over 300 km to Tsodilo and other inselbergs in the western Kalahari and over 200 km to the hills to the south and east of Makgadikgadi. The MSA sites on Ntwetwe Pan were not therefore the consequence of short, one- or two-day forays from more protective landscape contexts: rather they must have been part of longer movements into, through, or within, the open landscape.

The MSA archaeological sites on Ntwetwe Pan are not only rich in lithic materials but are also highly visible for much of the year, as well as numerous. They are part of the great potential of the southern African interior to contribute data, through systematic fieldwork, from open-air sites to address debates regarding early human behaviour, movement and decision making. In Makgadikgadi, the sites we have recorded and excavated have been exposed by the particular processes of lake sediment deflation that operate on the basin floor. Beyond this basin, the extensive sandy and vegetated tracts of the wider Kalahari landscape may tantalisingly also harbour archaeological sites that are more challenging to find and record. It is important, if we are to advance further interpretations of early human environmental adaptation, that research efforts focus on challenging environments and open-air sites. By doing so, our findings show that dry conditions presented opportunities for human behaviour and adaptation, and should not be seen as simply being obstacles and deterrents to mobility or resource use.

Author statement

DSGT, SLB, SDC and DJN conceived the original study and secured funding. DSGT, SLB, SDC, DJN, SM and SS conducted fieldwork and contributed to the various facets of analysis that constituted the overall project. DSGT led the overall paper conceptualisation and manuscript development. All authors contributed to the preparation and approval of the final manuscript.

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Declaration of competing interest

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

Data availability

Data will be made available on request.

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